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Geopolymer Nanoceramic Mortar Liner System for Corrosion Protection and Rehabilitation of Stormwater Piping

Final Report on Project F14-AR05

Clint A. Wilson, Jaclyn S. Mathis, Lawrence Clark,
and Anthony Delgado-Connor

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Geopolymer Nanoceramic Mortar Liner System for Corrosion Protection and Rehabilitation of Stormwater Piping

Final Report on Project F14-AR05

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Final report

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Corrosion Protection and Rehabilitation of Stormwater Piping"

Abstract

Many metal pipes and culverts on Department of Defense (DoD) installations are deteriorating due to corrosion. Repair often requires excavation, including roadways above culverts—a costly, messy, and disruptive approach. This project successfully demonstrated and validated a geopolymers liner system at Fort Bragg, NC. The evaluation focused on strength, corrosion resistance, and implementation to ultimately recommend use of geopolymers liners for DoD stormwater and wastewater infrastructure. A new Unified Facilities Guide Specifications (UFGS), UFGS 33 01 30.71 Rehabilitation of Sewer Utilities, was created to guide adoption of this technology, and a draft criteria reference request was created for UFGS 33 40 00 Storm Drainage Utilities. Caution is advised, however, for using a geopolymers liner in extremely acidic environments. Testing showed that geopolymers material provided higher compressive strength than typical concrete. Acid resistance could not be verified, however, although the product still may be suitable in wastewater environments. The primary advantage of a geopolymers liner is its ability to create a new structural pipe within the old, deteriorating pipe—a no-dig approach that saves costs. The geopolymers liner also provides other benefits such as no cold joints, faster cure time, and less down time. The project's return on investment is 7.73 over 30 years.

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Preface

This demonstration was performed for the Office of the Secretary of Defense (OSD) under Department of Defense (DoD) Corrosion Prevention and Control Project F14-AR05, “Geopolymer Nano-Ceramic Mortar Liner System for Corrosion Protection and Rehabilitation of Stormwater Piping.” The proponent was the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM), and the stakeholder was the U.S. Army Installation Management Command (IMCOM). The technical monitors were Daniel J. Dunmire (OUSD (AT&L)), Ramon Sison (IMPW), and Paul Richardson (DAIM-ODF).

The work was performed by the Engineering and Materials Branch (CEERD-CF-M), Facilities Division (CF), U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL. Significant portions of this work were performed by Mandaree Enterprise Corporation (MEC), Warner Robins, GA. At the time of publication, Vicki L. Van Blaricum was Chief, CEERD-CFM; Donald K. Hicks was Chief, CEERD-CF; and Kurt Kinnevan, CEERD-CZT, was the Technical Director for Adaptive and Resilient Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti, and the Director was Dr. Ilker Adiguzel.

The following individuals are gratefully acknowledged for their contributions to this project:

- Karl VanStavoren, Resident Engineer, U.S. Army Corps of Engineers (USACE) Savannah District (CESAS-CD-STS)
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The Commander of ERDC was COL Bryan S. Green, and the Director was Dr. David W. Pittman.

Unit Conversion Factors

Multiply	By	To Obtain
bars	100	kilopascals
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
pounds (force)	4.448222	newtons
square feet	0.09290304	square meters
pound	453.592	grams

1 Introduction

1.1 Problem statement

Many pipes and culverts on Department of Defense (DoD) installations are deteriorating due to corrosion. These units are exposed to a highly corrosive environment and demanding conditions such as freeze-thaw cycles, repetitive wet-dry cycles, traffic loading, pressure from movement in earth and rock embankments, mechanical wear from solids and grit in the stormwater, and chemical and biological elements. When stormwater structures fail, then sinkholes, road washouts, and flooding can occur. Repair often requires excavation to replace damaged culverts, including the roadways above them. This approach is costly, messy, and disruptive to installation traffic and other operations.

Maintenance and repair spending could be significantly reduced by use of an in situ rehabilitation method that requires little or no excavation of the degraded pipes. One candidate technology is a category of cementitious materials called geopolymers, which can be blended and applied by using techniques already available to civil engineering practice. Such applications would address one of the top 25 Army corrosion mitigation challenges: “Coatings and surface treatments are not intended to function over the entire spectrum of potential applications, so selecting the correct products for the job is a vital first step in preventing corrosion” (U.S. Army 2012). The demonstration/validation project reported here, funded by the DoD Corrosion Prevention and Control (CPC) Program, also addresses Capability Gap 6: “Improved operations and maintenance practice to reduce materials degradation” (U.S. Army, page 11).

A repair-in-place method would include the following advantages:

- less time and effort to execute than replacement,
- reduced installation operational downtime and traffic disruption,
- improved worksite safety, and
- lower maintenance costs.

Moreover, a properly designed geopolymer liner system could potentially restore structures to like-new operating condition and extend the service

life of system components. Geopolymer mortars provide high structural strength and improved corrosion resistance.

1.2 Objective

The main objective was to demonstrate and validate a commercially available geopolymer used as a liner product on a section of stormwater infrastructure at an Army installation to control system corrosion and degradation. Another objective was to survey and document the quality-control field test methods performed on-site. A third objective was to research the current maturity and adoption of the demonstrated technology.

1.3 Approach

This project included a field demonstration during 2014-15 to assess in situ performance and laboratory testing and to evaluate the material properties of the demonstrated geopolymer material. The selected demonstration site was Simmons Army Airfield, located on the southeast portion of Fort Bragg, NC, where a spray-applied geopolymer lining system was used to rehabilitate a 100 ft long, 4 ft diameter, corrugated metal, stormwater pipe.

Laboratory tests of the material were performed to investigate the geopolymer material's properties. Sulfuric acid resistance was investigated by measuring performance in conditions that simulate acidic environments such as those inside wastewater processing systems. Cyclic wet-dry drip tests and immersion tests were performed for the sulfuric acid resistance testing. In addition, compressive strength and flexural strength tests were used to validate product performance claims.

1.4 Metrics

The performance metrics for success of the demonstrated geopolymer liner system were: (1) corrosion resistance, (2) compressive strength, (3) flexural strength, and (4) ease and success of application. Corrosion resistance was evaluated in terms of resistance to highly concentrated sulfuric acid. ASTM C267-01, *Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings and Polymer Concretes*, is the closest industry standard to the chosen methodology. Because of practical limitations, the standard was adapted. Samples were immersed and observed for surface loss over time. Samples were also subjected to a drip test to simulate a thin

film interaction, which is more representative of what occurs in wastewater environments. This simulates (more closely than the standard tests) the oxidation-reduction reactions which ultimately lead to the aerobic production of sulfuric acid that attacks the crown of a pipe. This demonstration relied on visual inspection. Surface observations were also gathered via scanning electron microscopy and energy-dispersive x-ray spectroscopy.

Compressive strength was verified by testing geopolymers samples mixed at ERDC-CERL and samples collected in the field. Compressive strength tests based on ASTM C109 and ASTM C39 were performed on both sets of samples by ERDC-CERL and by a third-party testing company.

Validation of flexural strength was attempted by molding geopolymers beams and performing flexural beam testing at ERDC-CERL based on ASTM C78 and ASTMC293.

Ease of application was evaluated by comparing the application process to traditional means of pipe replacement. The success of the application was evaluated by the ability to complete the application in compliance with quality control and assurance as outlined by the product manufacturer's documentation. This document references several ASTM International standards for various concrete products (see listing below).*

Success was also measured by a visual inspection for cracks, conducted 12 months after the application.

* Due to the similarities between geopolymers and Portland concrete, many of the Portland concrete ASTM standards can be applied to geopolymers, but specific revisions are underway to include geopolymers. In particular, two committees are working to change current standards: (1) the ASTM Committee F36 for Technology and Underground Utilities and (2) the National Transportation Product Evaluation Program (NTPEP) of the American Association of State Highway and Transportation Officials (AASHTO) Spray Applied Structural Pipe Liners Technical Committee.

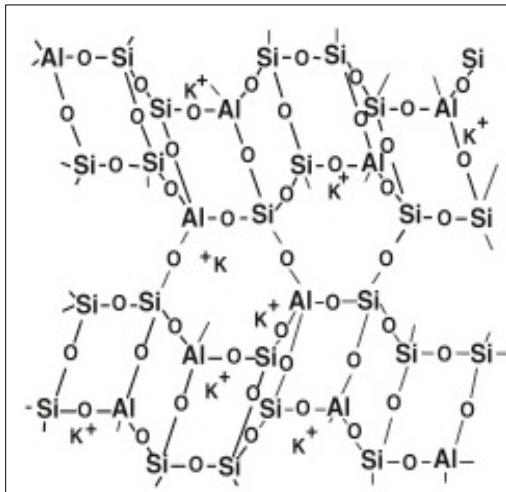
2 Technical Investigation

2.1 Technology overview

Geopolymers are a developing category of materials for use in high-performance coatings, fire-resistant coatings and tiles, thermal insulation, and composites for the repair and strengthening of infrastructure. Geopolymer materials offer new, beneficial, and sustainable solutions for the repair and maintenance of DoD infrastructure. Geopolymers are composed of chains or networks of mineral molecules linked with covalent bonds, similar to natural stone. They consist mainly of pozzolanic materials (glassy aluminosilicates). In conventional Portland cement concrete, pozzolans produce a gel-like material that decreases the porosity of the mortar by filling voids. In a geopolymer system, pozzolans act only as sources of reactive silica and alumina, which are readily available to polymerization reactions. The combination of pozzolanic activity and geopolymer formation makes geopolymer mortar or concrete stronger and more resistant to other chemicals than conventional Portland cement concrete (Gromicko and Shepard 2015).

There are multiple different classes of geopolymers. For this demonstration, the geopolymer class has a potassium-based poly (silicate-siloxo) structure (Davidovits 2008). A typical geopolymer structure is shown in Figure 1. While geopolymers are inorganic polymers, organics can also be incorporated to produce a hybrid material with unique properties. Geopolymers rely on thermally activated materials that dissolve in an alkaline activating solution and polymerize to create the hardened binder. The polymerization process can be a fast reaction that generates heat (Rangan 2008). For a pure geopolymer, water is not part of the final structure, unlike Portland cement-based concrete. Instead, water evaporates during curing and drying (U.S. DOT [Department of Transportation] 2010). Because of rapid chemical reactions and high heat generation, quality control is very important in the mixing, application, and curing processes of geopolymer-based materials.

Figure 1. Typical geopolymer structure.



Geopolymer lining systems are one proposed solution for repairing, rehabilitating, or protecting large pipe or culvert structures. The material is currently most suitable for pipes measuring 3–10 ft in diameter, and it can be spray-applied using commercially available spin casting equipment. In such uses, the geopolymer material is designed to provide high structural strength and suitable workability for field use. It is formulated to be optimally flowable, pumpable, and sprayable to facilitate in situ application.

In terms of this project, the term geopolymer concrete refers to the binding agent—a combination of Portland cement and materials capable of producing geopolymers. Although the proper ingredients for geopolymerization are available in geopolymer concrete, the product is equally capable of producing only alkali-activated hydrates of alumina and silica, such as calcium-aluminosilicate-hydrate (CASH) or sodium-aluminosilicate-hydrate (NASH). No attempt was made to verify this product's production of true geopolymers with potassium-based poly (silicate-siloxo) structures. The delivered dry goods will typically contain a minimum of 70% pozzolanic and inert materials consisting of slag, fly ash, fumed silica, sand, and crushed natural pozzolans. The manufacturer's safety data sheet (MSDS) for the product used in this demonstration can be found in Appendix A. The geopolymer material is engineered to provide high initial strength; excellent bonding, tensile, and elastic characteristics; and near-zero porosity. An additional structural benefit of geopolymer concrete is it will not produce a cold joint, which can be a common failure location. The geopolymer-Portland combination of the concrete studied here allows for chemical bonding across the interface, resulting in a monolithic structure.

A benefit of geopolymers over one competing product, cured-in-place pipe (CIPP), is that geopolymers contain no styrenes or leachable toxins and pass the Environmental Protection Agency (EPA) Toxicity Characteristic Leaching Procedure (TCLP). Furthermore, geopolymers concrete makers claim it is a greener product than typical concrete because it incorporates industrial waste byproducts such as widely-available fly ash (Louisiana Tech University 2009). Also, geopolymers manufacturing has a life-cycle greenhouse gas reduction potential of 90% compared to Portland cement. The concrete industry is responsible for approximately 5%–8% of human-generated atmospheric carbon dioxide (Louisiana Tech University 2009). Approximately one ton of carbon dioxide is produced per every one ton of Portland cement manufactured (Gupta 2016).

Geopolymer-based concrete is also expected to have a longer life cycle than Portland concrete (Louisiana Tech University 2009). Thus, it qualifies for Leadership in Energy and Environmental Design (LEED) credits (Henning and Vellano 2012). Technically, geopolymers are considered a “hazardous substance” because they are a type of ready-mix concrete product, but they are hazardous only in the same sense as Portland cement concrete. Occupational Safety and Health Administration (OSHA) considerations for the geopolymers-based concrete are similar to those for typical concrete projects.

The thickness and chemical mixture for each application is determined during design by considering the structural requirements, hydraulic requirements of the pipe, condition of the pipe to be rehabilitated, and any other pertinent local factors. Testing is accomplished by a combination of field and lab tests—typically compressive strength and possibly flexural strength. Calculations of the impact on hydraulic capacity of pipes are evaluated to account for not only the loss of pipe diameter but also the improved pipe surface roughness.

Geopolymer liners are now commercially available; however, there has been little or no use in DoD facilities. This work’s demonstrated liner system has been commercially available since at least 2011. It is now approved for use by Departments of Transportation (DOTs) in 10 states, including California and Florida. There are other commercial spin cast spray devices on the market similar to the type used for this demonstration. The equipment needed differs according to the material being applied, geometry of application location, pipe material, pipe function, and

pipe shape. Other companies offering or using versions of spin cast spray-ers include:

- Proform Pipe Lining Inc. – uses Centri-pipe
- CuraFlo
- TDT Plumbing - uses Triton Technologies Spin-Cast
- Southern Trenchless Solutions – InSitu-Cast™ Lining System
- Pipe Renovators
- Warren Environmental Inc.
- Centri-Pipe

2.2 Field work

The main objective of the field demonstration was to observe the installation and performance of the geopolymers liner system on a corrugated metal stormwater culvert approximately 100 ft in length and 4 ft in diameter (30.5 m x 1.2 m). Another objective was to survey and document the quality-control field test methods performed onsite. A third objective was to research the current maturity and adoption of this and competing products across the industry. The geopolymers liner was installed 8–12 December 2014 beneath a road at Simmons Army Airfield in North Carolina. No contracting or procurement problems were encountered.

2.2.1 Staging and culvert preparation

Coordination between the Simmons Army Airfield's DPW, the contractor, and the installer was required; however, no permits were necessary. No significant difficulties were encountered when preparing the site or installing the technology. To prepare the site, it was necessary to perform minor excavation at the entrance to the culvert and dig a sump pit to capture the flow of water going into the culvert for pumping across the road (Figure 2). The contractor positioned a specialized support truck at the site to provide water, compressed air, and electrical power. Along with the mixer and pump unit, pallets of geopolymers material were positioned at the site adjacent to the culvert.

Figure 2. Excavation and sump pump.



The culvert was pressure washed and visually inspected for damage, debris, and irregular geometry (Figure 3). Debris was swept and removed from the culvert. Any damaged, corroded or sharp edges were repaired using the geopolymer mix which was applied by hand using a trowel. Repairs were allowed to cure for 24 hours prior to the centrifugal spray application of the geopolymer liner. The damaged end of the culvert was also trimmed off to clean up the entrance and its appearance, as shown in Figure 4. A winch unit (used to pull a sprayer sled through the existing pipe) was positioned at the entrance to the culvert and staked to the ground (Figure 5).

Figure 3. Corrosion damage.



Figure 4. Entrance trimming.



Figure 5. Winch unit setup.



2.2.2 Application

Prior to application of the geopolymer liner, the installer drilled and screwed 2 in. (5.08 cm) concrete tapping screws into the galvanized culvert (Figure 6). The screws were installed at regular intervals along the culvert at the top and sides. The screws provided a method to measure the thickness of the spray application of geopolymer concrete to assure the desired thickness was achieved. The installer calculated that the liner of the

culvert would require approximately 2 in. (5.08 cm) of geopolymer material using their standardized design procedure.

Figure 6. Tapcon depth screws installed in culvert prior to geopolymer lining.



Dry geopolymer ready mix arrived at the site prepackaged in 50 lb (22.7 kg) bags. The material is also available in super-sized sacks for larger projects. The dry material was placed into an M-tec duo-mix 2000* (Figure 7), which is a continuous cement mixer that was used to mix and pump the geopolymer material to the centrifugal sprayer (Figure 8). A 1.5 in. (2.54 cm) inner diameter hose, meeting ASME B30.274, was used to transfer the material from the mixer to the spray nozzle. Three 50 ft (15.24 m) hoses were connected in series for this project. Water and power were supplied to the mixer from a support truck. Upon starting the mixer, the flow of water was manually adjusted until the mix was of the correct consistency. The recommended manufacturer's water-to-mix ratio was 18 lb (8.16 kg) water to 100 lb (45.36 kg) geopolymer mix, but the actual ratio used for this project could not be quantitatively verified. Instead, an experienced technician verified the consistency and adjusted the water addition and pump rates throughout the application, as he judged necessary. Upon achieving the desired consistency, the input water flow into the mixer was measured by the water meter on the mixer to be 160 gal/hr. In practice, there is a small water-to-mix ratio "window" in which the material can be successfully applied (0.18:0.20). If the material is too wet, it will run off the coated surface or sag. If the material is too dry, the pump or hose will

* Trade name of M-tec Global.

clog or the mixer may stop. Therefore, the water-to-mix ratio is somewhat self-regulating within the small range required.

Figure 7. Geopolymer continuous mixer and dry mix bags.



Figure 8. Geopolymer centrifugal spray applicator.



Application does not stop once it is started because of the risk of material hardening within the equipment. The demonstrated geopolymer concrete cures much faster than Portland cement. Three coats of the geopolymer liner were applied. The first layer was applied using 120 50 lb (22.7 kg) bags, with the application being pulled through the culvert at a rate averaging 32 s/ft (105 s/m). The second layer used 160 50 lb (22.7 kg) bags and was pulled through at a rate averaging 60 s/ft (197 s/m), and the third used 140 50 lb (22.7 kg) bags and pulled at an average rate of 42 s/ft (138 s/m). The application details are listed in Table 1. Material used

amounts represent the total, which includes minor material waste from initial mixing and material used to fill the pump and hose. Each layer was cured for 24 hours prior to applying subsequent layers.

Table 1 . Geopolymer mix application data.

Layer	Approx. Thickness (in./layer)	Material Used (lb.)	Average Pull-Through Rate (sec./ft)	Mixer Water Input (gal/hr)	Pump Hose Pressure (bar)
1	0.50	6,000	32	160	24
2	0.75	8,000	60	160	24
3	0.75	7,000	42	160	38

The centrifugal sprayer has a pneumatically powered rotating head that sprays the geopolymer concrete in a 360 degree fan pattern. The spray head is mounted on a tray that oscillates a short distance perpendicular to the spray pattern. The oscillation is mechanically controlled by an electric motor that oscillates approximately 3.6 seconds per cycle. The sprayer and tray are mounted on an aluminum sled that is custom-configured to the diameter of the culvert so that the spray head is aligned in the center of the culvert in order to equally apply the geopolymer concrete to the interior surface of the culvert. The sled is connected by a roller drive chain that attaches to the motor-driven winch outside the culvert entrance (refer to Figure 5). The winch has an adjustable speed control and utilizes a series of sprockets to draw the chain and pull the sled through the culvert. Prior to application, the sled is positioned at the far end of the culvert with the pneumatic hose, material pump hose and electrical cable connected to the system, the sled and centrifugal sprayer. A four person crew applied the geopolymer material to the culvert for this project: one person to operate the continuous mixer; one person to operate the chain puller; one person to monitor the spray applicator (in the culvert); and one person to manage the hoses as the sled is pulled through the culvert. The operator in the culvert was connected by radio headset to the operator on the mixer.

The final thickness was less than the 2 in. (5.08 cm) expected, but was within the tolerance of the design. According to the manufacturer's guidance, the minimum liner thickness for a pipe less than 54 in. (1.37 m) in diameter is 1 in. (2.54 cm). For a pipe greater than 54 in. (1.37 m), the minimum liner thickness increases to 1.5 in. (3.81 mm). The screws used for gauging material depth were not covered because the liner was not thick enough to cover them. Therefore, extra material was added with a

trowel to cover the screws and create a smooth surface. Typically, the screws would be covered by the liner without additional material being needed.

For disposal, the material can be watered down until it reverts back to sand. Or, the waste can be collected, allowed to harden, and then disposed. The disposal method will generally depend on local regulations. There are not large amounts of waste with this material, and it often is collected at the mixer or in 55-gallon drums to be hauled off site as a solid.

2.2.3 Field testing

For quality control, samples of mixed material and details about the installation were collected (see Table 2 in section 3.1.1). The installer utilized a third-party, independent testing laboratory to conduct on-site quality control. ASTM C172 could not be performed in accordance with the requirements for the section pertaining to “Sampling from Continuous Mixers.” This occurred because there was no reasonable way to interrupt the process to take samples without disconnecting the hose and because samples could not be taken from the (spinning) sprayer head. Additionally, the geo-polymer mix begins to harden immediately after mixing, unlike Portland concrete. Thus the mix becomes difficult to work within 5–10 minutes, preventing samples of the mix from being taken throughout the application process.

2.2.3.1 Initial sample collection

For this project, samples were taken in the very first section of the mixer’s continuous discharge hose after the desired consistency was achieved and at least 5 ft of material was pumped in the hose. The sample was collected directly from a 5 ft hose attached to the mixer pump. Once the sample was collected, the transfer hose was disconnected, the primary hose to the centrifugal sprayer was attached, and the application commenced.

2.2.3.2 Slump testing of samples

A slump test was accomplished (Figure 9) with the sampled material in accordance with ASTM C143, “Standard Test Method for Slump of Hydraulic-Cement Concrete.” A glass thermometer was inserted into the sampled mix to measure the mix temperature in accordance with ASTM C1064,

“Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete.” Following the slump test, the thermometer was removed and temperature recorded.

Figure 9. Slump test being performed in accordance with ASTM C143 Standard Test Method.



Seven test cylinders that were 4 in. diameter x 8 in. long (10.16 cm x 20.32 cm) were prepared each day in accordance with ASTM C31, “Standard Practice for Making and Curing Concrete Test Specimens in the Field.” The cylinders were stored on-site in a Styrofoam container to prevent their temperatures from dropping overnight. The cylinders were later transported to the independent laboratory and tested for compressive strength in accordance with ASTM C39, “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.” The field sample tests were in accordance with the technical data provided by the manufacturer (Appendix A). Results are listed in Section 3.1 and Appendix C, respectively.

2.3 Performance monitoring and testing

As noted in the sections below that describe testing, standards referenced by ERDC-CERL during this work include the following:

- ASTM C109 - Standard Test Method for Compressive Strength of Hydraulic Cement Mortars
- CECW-ED Engineer Manual 1110-2-2902: Engineering and Design, Conduits, Culverts, and Pipes

- ASTM C76 - Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe
- ASTM C595 - Standard Specification for Blended Hydraulic Cements

Note that the CECW-ED Engineer Manual references ASTM C76 and leads to ASTM C595 which states pozzolans are permitted materials for use in cements and concretes.

2.3.1 Compression testing

The compressive strength of the liner was evaluated. The third-party testing company, Engineering Consulting Services (ECS) in Fayetteville, NC, performed compression testing on the cylinders after the material cured for 7, 28, and 56 days. Additionally, 2 in. cubes of the geopolymer material were molded in the field for further validation of the compressive strength by ERDC-CERL. This group was tested on days 7, 29, and 85 due to availability of the testing equipment. A 50 kip (4.44 kN) load frame at ERDC-CERL was used for this testing, and ASTM C109 was used as a guide. The loading rate was 0.05 in./min. For comparison, ERDC-CERL also mixed geopolymer mortar in the laboratory and performed compression testing for that group of samples as well. The geopolymer mortar mixed in the lab required a water-to-cement ratio of 0.20. A drill with a mixing paddle was used to thoroughly mix the mortar. Due to the fast-setting nature of the mortar, the sample group was made of three smaller batches using 1,000 g of geopolymer mix and 20 mL of tap water. After mixing, the material was transferred into the molds, filling each mold about halfway. The material was tamped down, and then filled the rest of the way. Excess material was removed, and the material was tamped again. Each batch yielded four cubes. Additionally, a test was conducted by the manufacturer to examine the effect of different water content ratios on the strength of the material after curing 28 days.

2.3.2 Flexural testing

The goal of flexural testing was to explore whether beam breaking tests, typically used with Portland cement concrete (PCC), can be practically performed on the geopolymer concrete. The flexural testing was performed by ERDC-CERL, and the testing consisted of four trials using geopolymer mix and four trials using PCC.

For comparison, PCC (Quikrete brand) samples were prepared first, using an electric drill and mixing attachment to mix the powder with the appropriate amount of water (4,100 mL water per 50 lb of mix). Two to three 50 lb bags were mixed at one time. Then, the mixture was shoveled into six 6 x 6 x 22 in. metal beam forms. Tamping was performed two times—when the mold was halfway full and entirely full—by using a rod and a rubber mallet. The surface was smoothed. After 24 hours, the beams were removed from the mold and immersed in water (Note that the beams were not immersed for trials one and two). The beams were tested by using a combination portable beam tester in the third-point flexural loading configuration shown in Figure 10. Each beam was placed in the test apparatus, and the hydraulic hand pump was used to apply pressure until the specimen failed. The following information should be noted about the test apparatus: “The hydraulically loaded unit does not strictly comply with ASTM/AASHTO requirements [such as ASTM C78 or C293], but results compare favorably with more expensive machines meeting the standards” (Certified Material Testing Products 2017).

Figure 10. Flexural testing apparatus setup with a broken beam.



Each trial consisted of beams that were cured for 1, 3, and 7 days. The number of days in curing was intentionally reduced from the typical 3, 7, and 28 days because geopolymers concrete is stronger and gains strength faster than PCC.

A similar process was used for the geopolymers material. The water ratio used for the geopolymers was 4,100 mL water to each 50 lb bag of powder. Note that the gauge malfunctioned for geopolymers trials one and two, but it was repaired prior to trials three and four. Moreover, for trials three and four of the geopolymers beams, a different mixer attachment was used to improve shear levels while mixing. The molds were entirely filled before tamping, and only the rubber mallet was used for tamping. For trial three, the beams were put into water 24 hours after molding. For trial 4, the beams were immersed in water after approximately one hour while still inside the molds, as the material was not hardened yet. These changes in procedure were an attempt to improve beam performance since the geopolymers was found to not cure evenly or completely, due to either temperature effects, or dehydration of the sample, or both. For more information, see flexural testing results in section 3.1.3 and lessons learned in section 3.2 of this report.

2.3.3 Corrosion (sulfuric acid resistance) testing

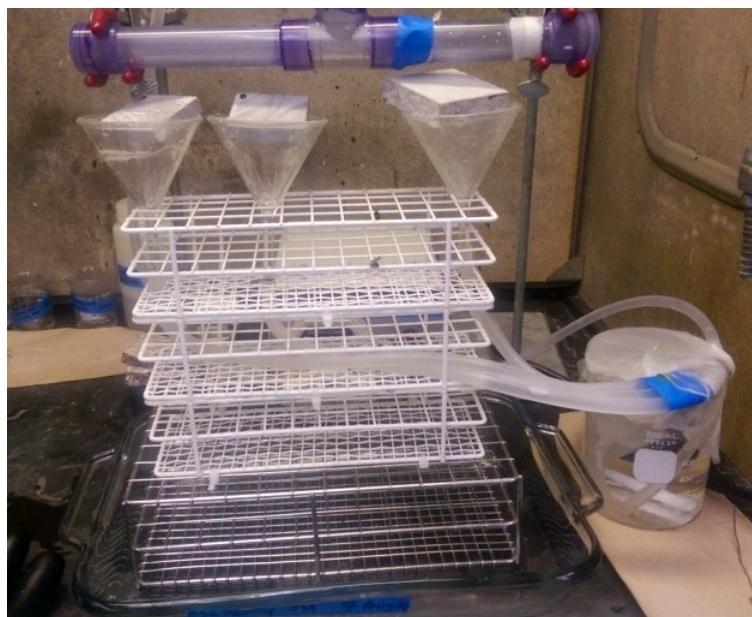
A sulfuric acid resistance test was conducted to determine the performance of the geopolymers liner in resisting corrosion within an acidic environment, such as might be found in parts of a wastewater system. A testing apparatus was created to establish a thin film of sulfuric acid in the head-space of a pipe, to roughly simulate biogenic sulfide corrosion in a laboratory. This apparatus used a timer and pump to create cyclic periods of wet and dry surfaces on the samples.

The testing apparatus was designed for sulfuric acid to flow in a closed circuit from a beaker, through the pump and clear PVC schedule 40 pipe, onto the samples, through a funnel and tube, and back to the beaker (Figure 11). The pump was a Masterflex® lab scale (L/S), economy pump with a Masterflex L/S Easy-Load pump head.* The tubing used was Masterflex C-Flex Ultra Tubing, size 17. The experiment utilized three funnels

* Masterflex is a registered trademark of Cole-Parmer of Vernon Hills, IL.

to hold the samples and to collect the acidic solution. The beaker was covered with Parafilm to provide a seal to prevent loss of solution as well as anchor the tubes in place.

Figure 11. Laboratory apparatus designed for thin-film acid conditions.



Before starting the testing, the masses of two geopolymers concrete samples and one PCC sample were measured by a digital balance. A sulfuric acid solution was prepared on a stir plate using 600 mL of water and 6–8mL of concentrated sulfuric acid (96.5%). Titrations were performed to determine the concentration of the acid, since the pH was too low to be accurately measured using a pH meter. Sodium hydroxide was used as the titrant, and phenolphthalein was used as the indicator. The average concentration of the stock solution was 9.6% sulfuric acid. This is an accelerated test, as 9.6% sulfuric acid solution is too strong to be found in a wastewater system or other water infrastructure; the pH in an actual wastewater system is likely 1.0 (Attiogbe and Rizkalla 1988).

Samples were placed in the funnels at a slight angle in order to let the acid drain off. Two mechanical timers were used to regulate the pump. The first timer was used to run the pump in time intervals of 5 minutes on, 12 minutes off, and then 30 seconds on, and 12.5 minutes off over the course of 30 minutes. The second timer ran the experiment from 7:00 a.m. until 4:30 p.m. each day. This simulated a thin film of acid solution repeatedly

applied to the samples for the duration of the experiment. After experimenting with settings, the pump speed was set to approximately 1.2 to achieve a consistent drip of acid onto the surfaces of the samples.

The experiment ran in this configuration from Monday through Friday for three weeks. At the conclusion of each week, the timers were unplugged, the samples were rinsed with deionized water, brushed with a wire brush, and left to dry for the weekend. The mass of each dry sample was measured on the following Monday afternoon (samples after week three of the first test were measured on Tuesday during the first round due to availability). At the beginning of each week, each sample was moved over one funnel to the right so that each sample was placed on each funnel for one week. This movement was used to minimize any potential impact from uneven drip rates on the samples. To begin the third week of testing, a new solution was prepared using the same method previously described. A new solution was prepared because a significant amount of volume was lost due to a clog of sloughed geopolymers in a funnel. The entire test was repeated a second time with the same procedure. The results were not as expected, so the procedure was repeated a third time, but using samples sent by the manufacturer.

Following the acid test, a 1 x 1 in. (2.54 x 2.54 cm) piece was cut from each sample. A geopolymer control sample was cut down to size for comparison. A PCC control sample was also used. Approximately one week before characterizing the samples via scanning electron microscopy (SEM) and energy dispersive X-Ray spectroscopy (EDS), the sample pieces were placed in a vacuum oven to reduce their moisture content. This moisture reduction enabled the samples to be effectively observed when using SEM and EDS techniques.

An acid immersion test of the geopolymer and PCC samples was also conducted as an alternative to the cyclic wet/dry process testing. This experiment was performed by using the same mix for the acid solution that was used for the drip test. Equal amounts of the solution were poured into three beakers. A sample of geopolymer concrete was placed in two beakers and a sample of PCC was placed in the third for three weeks and observed visually each week. Mass loss was measured when possible. This test was conducted twice. One test used samples collected from the field test at

Simmons Army Airfield, and the other used samples sent by the manufacturer. In both cases, 2 in. cubes were cut into thicknesses of about 0.5 in. for the testing.

The manufacturer reviewed ERDC-CERL's test procedure and results. One explanation for poor acid resistance may be the use of a lower-density geo-polymer mix for the samples tested. There was a foaming agent included, and the current formula also includes another agent to counteract the density reduction from the foaming agent.

2.3.4 Field monitoring

Inspection of the demonstration pipe was performed in December 2015 at the conclusion of the 12-month monitoring period. See chapter 3 of this report for discussion of results and lessons learned.

3 Discussion

3.1 Results

3.1.1 Field application

The application in the field went smoothly, with no major issues. The final thickness was less than the guide screw depth of 2 in., but the thickness was within the tolerance of the design. Also, several suggested data collection fields recommended by the manufacturer were not measured by the installer during the field application process, as shown in Table 2.

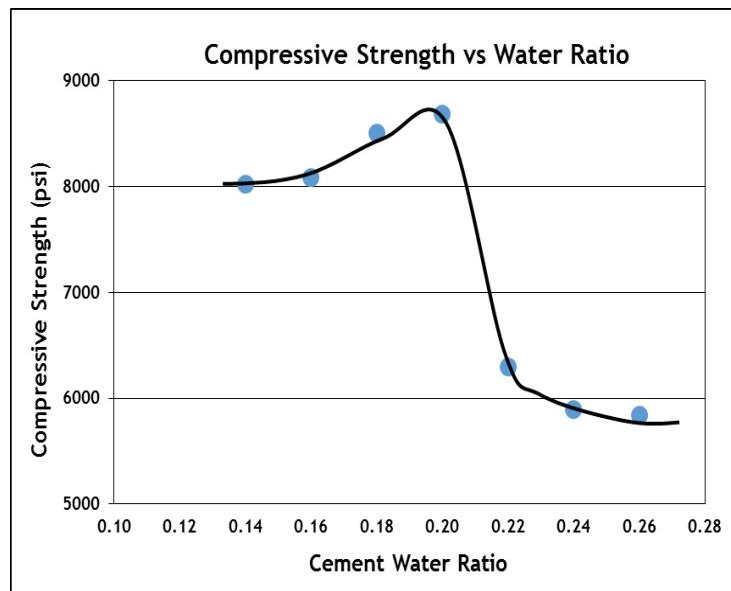
Table 2. Field application data to collect, as recommended by manufacturer.

Data to be Recorded per Manufacturer	Data Actually Recorded
Water addition rate	160 gal/hr
Pump motor speed	Not recorded
Pump distance	Not recorded
Slump test (in.)	5, 7, 7.5
Batch water temperature (°F)	Not recorded
Dry powder before mixing temperature	Not recorded
Ambient air temperature within pipe	Not recorded
Ambient air temperature at point of mixing (°F)	55, 45, 50,
Temperature of sampled material (°F)	62, 56, 60,

3.1.1.1 Effect of water ratio during application

The geopolymmer material's water content is somewhat self-regulating during application, because a mix that is either too wet or too dry cannot be applied. If the material is too wet, it will not stick to the pipe; if it is too dry, it won't spray properly. Thus, there is a narrow range of proper cement-to-water ratio (0.18–0.20) that will ensure proper application (U.S. Army 2012). A compressive strength vs. cement water ratio test was performed by the geopolymmer manufacturer, with results shown in Figure 12. As would be expected, the curve shows that compressive strength rose at a cement-to-water ratio of .18, and the highest compressive strength occurred at a ratio of .20.

Figure 12. Compressive strength vs. water ratio curve (Milliken Infrastructure Solutions, LLC).



3.1.2 Compressive strength

As stated previously, a third party (ECS) tested the compressive strength of the geopolymers cylinders that were molded in the field. For further validation, ERDC-CERL also performed compressive strength tests on samples collected from the field and on samples prepared in the laboratory. It should be noted that 2 in. cubes were used for testing in the ERDC-CERL laboratory instead of cylinders. Table 3 shows the average compressive strengths tested at 7, 28, and 56 days after the geopolymers were mixed.

Table 3. Tests of average compressive strength (psi) over time.

Tester (and Sample Type)	Day 7 (psi)	Day 28 (psi)	Day 56 (psi)
ECS (field cylinder samples)	7,030	10,500	Not performed (met design strength of 8,000 psi after 28 days)
ERDC-CERL (field cylinder samples)	6,298	8,982 (Day-29)	10,422 (Day 85)
ERDC-CERL-(lab-mixed cube-shaped samples)	6,949	8,791	Not performed (met design strength of 8,000 psi after 28 days)

For reference, the typical compressive strength of PCC is 3,000–6,000 psi (20.68–41.37 MPa), depending on the mix (Engineering Toolbox 2017).

Thus, Table 3 shows that the geopolymer material can be 1.5–3 times as strong as typical concrete. This superior strength provides opportunities for geopolymer material uses that are not possible with regular concrete.

3.1.3 Flexural strength

Results from ERDC-CERL's four trials of flexural strength testing of each material in a beam shape are shown in Table 4. The Quikrete material gained flexural strength during curing, and it reached a relatively high percentage of its strength by day 7. For the first two trials, the geopolymer material's strength did not increase over time. However with improved mixing techniques used in Trials 3 and 4, the geopolymer material gained strength as expected. At day 7, the geopolymer material's flexural strength is expected to be 900 psi, according to the manufacturer's technical data sheet (Appendix A). As shown in Table 4, the expected strength of 900 psi was exceeded on day 7 during Trials 3 and 4. After 28 days, the flexural strength is estimated to reach 1,300 psi, according to the geopolymer manufacturer (see Appendix A).

Table 4. Flexural testing result averages, by type of material.

Quikrete (PCC)	Day 1	Day 3	Day 7
Trial 1	480	700	1,190
Trial 2	450	870	1,150
Trial 3	120	610	930
Trial 4	310	670	860
Geopolymer	Day 1	Day 3	Day 7
Trial 1	580	460	480
Trial 2	600	560	525
Trial 3	560	970	1,150
Trial 4	495	970	1,255

Uneven drying (or curing, or shrinkage) was observed in most of the beams, which was easily visible on the beams in the form of a “U” pattern (Figure 13). Furthermore, the beams fractured along this line of color change.

Figure 13. Two examples of uneven drying and shrinkage cracking (note the U-shape easily visible in sample on right).



3.1.4 Corrosion resistance (acid tests)

3.1.4.1 Pulsed/cyclic drip test

In addition to utilizing a standard immersion test (see section 3.1.4.2), ERDC-CERL developed another acid resistance test to more closely resemble field conditions. This additional test was designed to represent a thin film condition at the inside surface of the crown of a pipe. In order to simulate this, a sulfuric acid pulsed/cyclic drip test was performed. In this experiment, mass loss was one metric used to evaluate the acid resistance of the PCC compared to the geopolymers material. Table 5 shows the mass lost by each sample weekly over the course of the first round of the experiment. Table 6 shows the results from the experiment's second round. The experiment was also repeated with samples from the manufacturer for a third round of testing, with those results shown in Table 7.

The results show only a minor effect on the PCC samples from acid, while each geopolymers sample lost more than 30% of its original mass. It can be concluded that the acid at this strength and exposure type had a much greater effect on the geopolymers concrete than the PCC. However, it may be important to note that the PCC sample was cured approximately six months longer than the geopolymers samples.

Table 5. Mass loss of samples throughout the first round of the resistance cyclic acid drip experiment.

Sample Material	Initial Weight (g)	Week 1 (g)	Week 2 (g)	Week 3 (g)	Total Change (g)	Total Change (%)
Geopolymer A	41.44	36.54	32.18	23.29	18.15	43.8
Geopolymer B	68.64	63.44	57.05	45.6	23.04	33.6
Portland Concrete	139.94	140.76	138.7	134.79	5.15	3.7

Table 6. Weight loss of samples throughout second-round trial of the acid resistance cyclic experiment.

Sample Material	Initial Weight (g)	Week 1 (g)	Week 2 (g)	Week 3 (g)	Total Change (g)	Change (%)
Geopolymer C	56.33	47.45	37.52	25.40	30.93	54.9
Geopolymer D	64.65	56.60	48.44	36.96	27.69	42.8
Portland Concrete	125.80	126.32	124.67	116.55	9.25	7.4

Table 7. Weight loss of samples throughout third-round trial of the acid resistance cyclic experiment, using manufacturer's samples.

Sample Material	Initial Weight (g)	Week 1 (g)	Week 2 (g)	Week 3 (g)	Total Change (g)	Change (%)
Geopolymer 1	62.03	56.8	47.78	33.03	29	46.8
Geopolymer 2	63.36	57.26	48.14	36.13	27.23	43.0
Portland Concrete	70.95	67.73	62.39	55.95	15	21.1

3.1.4.1.1 Visual inspections

Additionally, visual inspections were performed throughout the acid resistance testing. It was visually observed that the geopolymer concrete was deteriorating under the acid. In Figure 14, a picture of the geopolymer concrete during the first week of acid resistance testing can be seen on the left. On the right is the same sample during the third week of testing (both photos are from first trial). The geopolymer sample began with a fairly smooth, grey surface. As seen in Figure 14 (right), the surface is no longer smooth, the color has changed, and the surface is covered in loose material.

Figure 14. Geopolymer sample during first week of testing (left) and visual evidence of mass loss and surface change of geopolymer sample (right).



After the first week of testing during the first-round trial, the surface of the geopolymers samples were not as smooth as they were at the beginning of the week. The material appeared to have absorbed some of the acid solution and looked swollen. Where the droplets of acid were striking the samples, a small divot started to form on the surface. The PCC sample was partially covered with a turbid liquid, and fine corrosion products were loosely attached. When rinsing and brushing the geopolymers samples, nearly the entire surface was covered in a layer of loose corrosion product. This loose material was removed by brushing. The PCC did not lose as much material when brushing it off as did the geopolymers sample; however, there was still some loss of material on both the surface exposed to the acid and the underside of the sample. After letting the samples dry for 2–3 days, the geopolymers turned a bleach-white color, and aggregates were clearly exposed. The PCC was also almost white in color.

The second week of testing had similar results to the first week. Both samples continued to deteriorate under the acid, although the geopolymers concrete seemed to be deteriorating at a faster rate than the PCC. Debris from the PCC and the geopolymers concrete began to collect at the bottom on the funnels and in the acid recollection tubes. The geopolymers samples were visibly thinner than at their start. Roughly three-quarters of the acid had been lost at this point, to either splashing, evaporation, or reaction.

To begin the third week of testing, a new acid solution was prepared in the same way that it was previously prepared. Also, the main pump tube was replaced due to wear from the pump. On Tuesday of the third week, the PCC funnel clogged with debris from the sample. This clog caused acid to overflow. Roughly two-thirds of the acid was lost. However, there was enough acid left to continue the week of testing without creating a new solution of acid. The second round of testing led to very similar results, including a clog near the end of the testing period.

3.1.4.1.2 Electronic surface scans

Scanning electron microscope (SEM) pictures characterized what occurred on the surface of the sample. The results are displayed for the first round of the PCC samples in Table 8 and the geopolymers samples in Table 9. An important item to note is the observance of the fibers that became exposed after the geopolymers were subjected to sulfuric acid. The PCC showed signs of attack to the binder, and some aggregates were exposed. Table 10

shows the element maps obtained via EDS for the PCC and the geopolymer, before and after exposure to sulfuric acid. The geopolymer experienced a significant surface change. The surface was initially uniform but as mass was lost, fibers became exposed. The PCC also experienced some change at the surface as the outer layer deteriorated, but it was not as significant. SEM results for Trials 2–3 are shown in Table C6 in Appendix C. EDS results for additional trials are displayed in Table C7 and Table C8, also in Appendix C. The additional trials showed similar results for both characterization techniques.

Table 8. Comparison by SEM of the PCC samples, before and after exposure to acid.

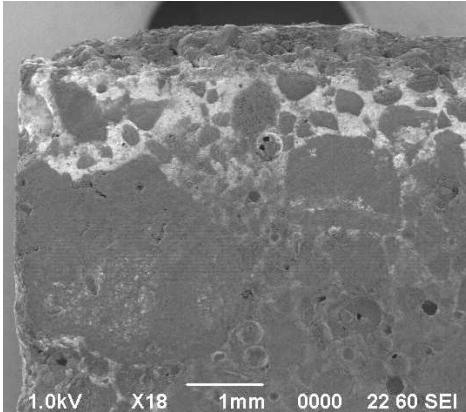
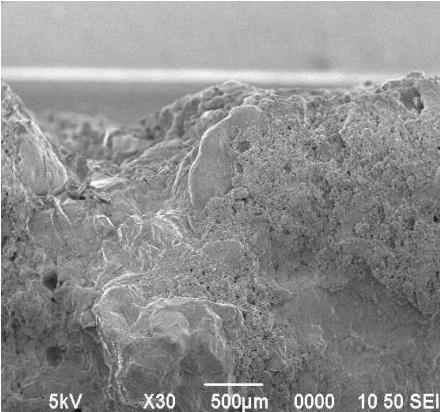
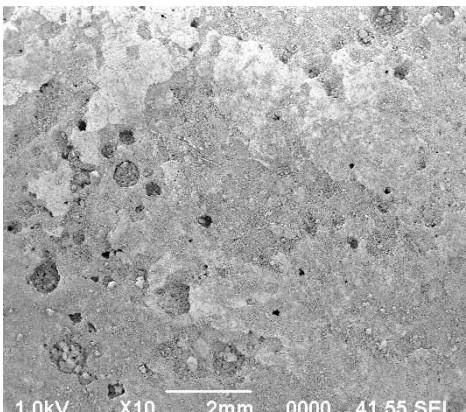
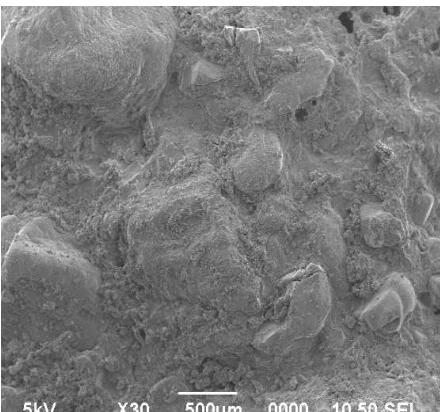
Description (L-R)	Unexposed to Acid	Exposed to Acid
“Naked eye view” of Portland Concrete unexposed (left) and exposed to sulfuric acid (right).		
Portland unexposed vs. exposed, profile SEM view (some deterioration occurred).	 1.0kV X18 1mm 0000 22 60 SEI	 5kV X30 500μm 0000 10 50 SEI
Portland Unexposed Vs Exposed, Alternate SEM View (surface became more rough, some mortar lost)	 1.0kV X10 2mm 0000 41 65 SEI	 5kV X30 500μm 0000 10 50 SEI

Table 9. Comparison by SEM of the geopolymers samples, before and after acid exposure.

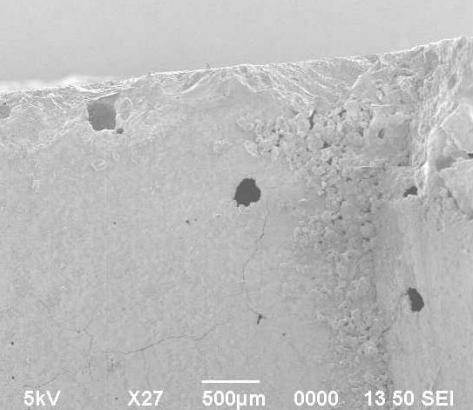
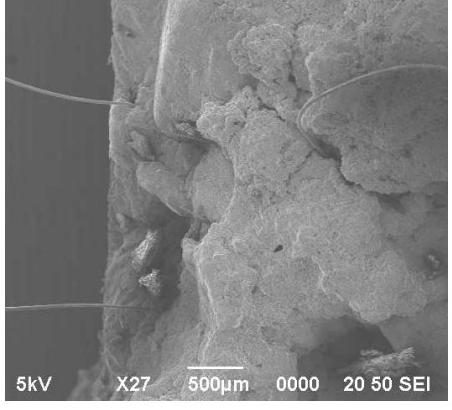
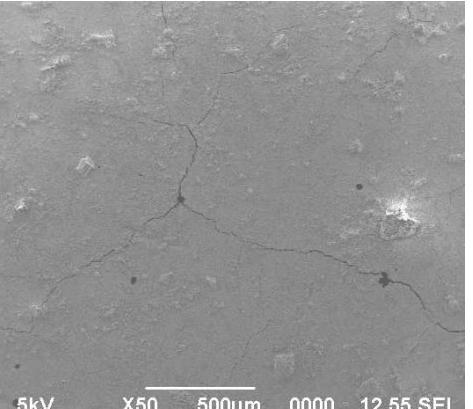
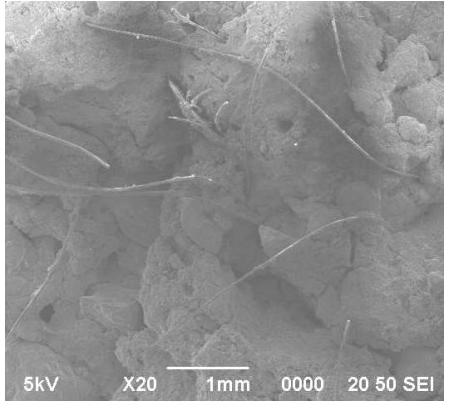
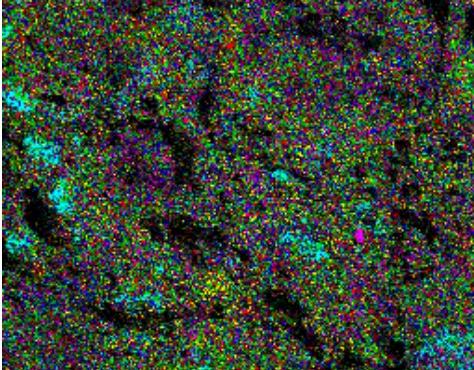
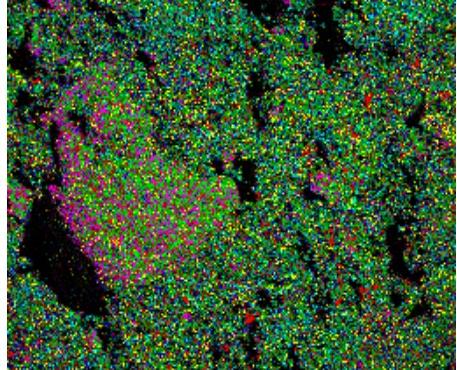
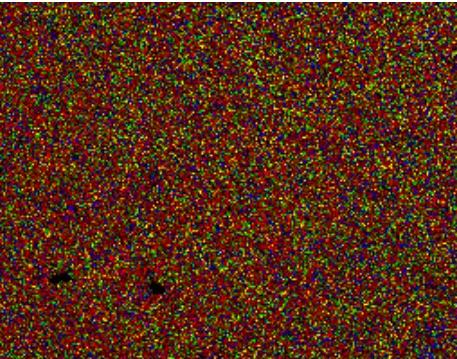
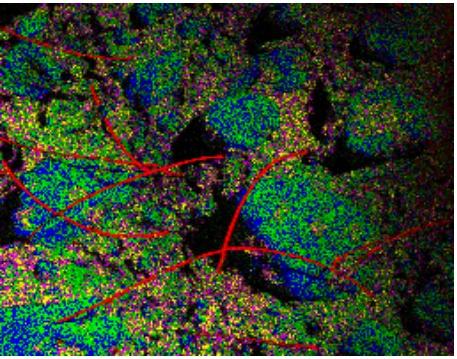
Description (L-R)	Unexposed to Acid	Exposed to Acid
"Naked eye view" of geopolymers concrete unexposed and exposed to sulfuric acid.		
Geopolymer control vs. exposed, profile SEM view (surface deteriorated, exposing fibers).	 5kV X27 500µm 0000 13.50 SEI	 5kV X27 500µm 0000 20.50 SEI
Geopolymer unexposed vs exposed, alternate SEM view (initial surface deteriorated, exposing fibers).	 5kV X50 500µm 0000 12.55 SEI	 5kV X20 1mm 0000 20.50 SEI

Table 10. EDS characterization of the samples before and after acid exposure.

Description (L-R)	Unexposed to Acid	Exposed to Acid
PCC EDS composition map; minimal surface change does occur.		
Geopolymer concrete EDS composition map; Uniform layer at first but after exposure, significant material degradation occurs, revealing more aggregates and the fibers.		

3.1.4.2 Acid immersion test

An acid immersion test was also performed, and the results from Trial 1 and Trial 2 are shown in Table 11. The mass loss rate was much greater in immersion test than the cyclic test. The geopolymer also did not perform as well as the PCC samples. Additional images from acid resistance testing and characterization are shown in Appendix C.

Table 11. Initial and final mass from geopolymer immersion of field samples.

Sample	Initial Mass (g)	Final Mass (g)	Mass Loss (g)	Mass Loss (%)
Trial 1				
Geopolymer 1	54.46	2.99	51.47	94.5
Geopolymer 2	61.89	8.28	53.61	86.60
Portland	148.46	105.16	43.3	29.2
Trial 2				
Geopolymer 3	60.86	8.52	52.34	85.90
Geopolymer 4	68.60	1.30	67.30	91.8
Portland 2	71.43	Unmeasurable	Unmeasurable	Unmeasurable

3.1.5 12-month reassessment

The culvert that was rehabilitated with the geopolymer liner was visually inspected to assess its condition on 17 December 2015, which was 12 months after application. The culvert was in excellent condition, with the exception of some minor cracking near the joint of the center pipe section. These cracks likely resulted from the structure trying to relieve the buildup of residual stresses, which is a favorable condition. According to Edvardsen (1999), such cracks can sometimes heal themselves when moisture is present via a capillary action process called autogenous healing, in which the moisture reacts with previously unreacted material in the crack. It is common for these cracks to heal themselves, but then to appear elsewhere in the pipe (Edvardsen 1999). Documentation of the observed cracks for this study can be found in Table C9.

The geopolymer liner appeared overall to be intact, and it provided effective rehabilitation of the corroded culvert. While visual inspection alone only allows a limited assessment of performance, the liner's visible surfaces looked good.

3.2 Lessons learned

Several lessons learned are related to the quality control (QC) and quality assurance (QA) during the field demonstration. First, it seemed that QA procedures were in place, but in reality, significant QC procedures were lacking.

ASTM C172 could not be accomplished because there was no way to divert and interrupt the process to take samples. The material also begins to harden immediately, which also prevents samples from being taken throughout the application process. The manufacturer of the geopolymer recommends the following alternatives for the ASTM C172 requirements:

- Strength tests require a minimum of 1 ft³ (28 L) of material to sample.
- Samples should be collected at the end of the hose near the discharge point. Only in rare circumstances where this may not be possible, a sample may be drawn from a section of hose at minimum 50 ft (15.24 m) from the mixer/pump. All samples points and approximate distance from the mixer pump must be noted. More information is included in Appendix B.

Another lesson learned is slump testing is not an appropriate quality control method. The material cures quickly and is very time dependent, making repeatability difficult. It is also looser than typical concrete in order to be spray-applied, and so does not slump test consistently.

As shown in Table 2 (section 3.1.1), there are several items of information that should be collected. However, many were not recorded. The contract should require the information be collected and that the contractor keep a site log. The main use of this information is for assisting in the evaluation of determining deficiencies of the finished product should they occur (not controlling the process).

The manufacturer warrants the product to be free of material and manufacturing defects. In the case of a defect, the manufacturer's liability is limited to replacement of the product, ex-factory. There is no warranty to merchantability or fitness to a particular purpose (see technical data sheet in Appendix A). Thus, a Licensed Professional Engineer (PE) should be required to certify the design. The design should also address how the liner will alter the hydraulic capacity, including both negative effects of a smaller pipe diameter, and positive effects due to improved Manning's coefficient/roughness. The design thickness may be guided by rules of thumb such as those encountered in this effort, but a PE is should still be required to certify the design.

During the acquisition process, ensure that the application company is certified by the manufacturer and has had experience with this type of material. References should be required. With regard to contracting, a market survey was conducted identified multiple competitors. Thus, sole-source procurement should not be necessary as the technology has matured enough to sustain competition within the industry.

ASTM C595 indicates the approval of the use of pozzolans combined with Portland cement. However, section 7.1.3 of C595 specifies the pozzolan constituent be 40% by mass or less of the cement mixture. In this case, the pozzolanic material was approximately 70% of the mixture. The allowed ranges of pozzolanic material for a geopolymer concrete may require further investigation and classification.

The flexural strength results for the first two trials of the geopolymer samples were lower than expected, and lower than typical concrete. Flexural testing of large 6 in. beams is not recommended as a field test. However, it may be considered a useful test if certain measures are taken. Lessons learned include:

- Using a spray nozzle attached to the large mixer would be the best method of sample collection since the application method provides additional benefits, such as compaction.
- If a spray nozzle is unavailable or the material is mixed manually for testing, a drill attachment that provides high shear mixing is important. This is not required with regular concrete because regular concrete has larger aggregate which aids in mixing. If high shear mixing is not achieved, the early stage results are not as good as they should be because the chemical reaction takes longer.
- Large sample mass can have adverse effects. Making 6" x 6" x 20" samples created a significant amount of heat which can lead to early dehydration. Consequently, this takes away moisture necessary for cross linking to occur in order to build strength. If using large samples, they should be moisture cured either by saturating with water and wrapping with plastic and burlap or immersed in water. If a sample is immersed, it should be taken out of the water one day prior to testing (samples from this experiment were not removed from the water until the test occurred). Note that the beams used in flexural testing are not very representative of how the material is configured in field applications.

- Never use a rod to tamp during sample preparation as performed when using typical concrete. This is because the geopolymer material does not have large aggregates like Portland concrete. When tamping occurs, the large aggregates can help distribute air. Without large aggregates, tamping using a rod can trap air instead of expelling it. It is better to tamp with a rubber mallet/vibration. In this demonstration, rod tamping was used for samples collected for compressive strength. Additionally, do not wait to tamp until the molds are full, and only perform one pour.
- When a shear mixing attachment, moisture curing, and only using the mallet for tamping, results did improve.
- Samples prepared for flexural testing exhibited uneven drying/shrinkage with a boundary forming. Failure repeatedly formed along this interface.

In addition, pre-packaged bags of geopolymer material are required; no on-site mixing of raw material should be allowed other than the addition of water. This is required since the chemistry of the material significantly affects the performance of the product and must be closely controlled.

Another lesson learned is that autogenous healing has only recently received recognition and research in the last 10 years, similar to the advancement and availability of blended Portland cement and geopolymers. Some research indicates that geopolymer aluminosilicates have even better autogenous reactions than regular concrete and other types of polymer concrete.

4 Economic Analysis

4.1 Costs and assumptions

Total actual costs for the execution of this demonstration project are shown in Table 12.

Table 12. Demonstration project costs.

Description	Funding Source		Total (\$k)
	OSD (\$k)	DPW (In-Kind Match ⁽¹⁾ (\$k)	
IN-HOUSE			
Labor (O&M)	50 ⁽²⁾	--	50 ⁽²⁾
Labor (RDT&E)	30	--	30
Awards	--	--	--
Purchases (O&M)	5	--	5
Travel / Training (O&M)	10	--	10
Travel / Training (RDT&E))	5	--	5
Misc (RDT&E)	20	--	20
OTHER GOVERNMENT AGENCIES			
OGA (RDT&E)	5	--	5
CONTRACT			
Private Industry (O&M)	125	245	370
College / University	--	--	--
FFRDC	--	--	--
Other Non-Profit	--	--	--
TOTAL (\$k)	250⁽²⁾	245	495⁽²⁾

¹Rehab of stormwater culverts via Fort Bragg DPW contract actions.

²This includes \$5K that will be a separate future funding requirement to complete the ROI Reassessment reports due two years after the final technical report is published.

4.1.1 Alternative 1 (baseline case)

The baseline option is to replace failing storm culverts by conventional open cut methods. This method is currently employed at Fort Bragg and other locations whenever the condition of the existing pipe or other factors does not permit using a different rehabilitation technology. Roadways must be dug up and then replaced, as will embankments, fill, and the cul-

vert itself. There are associated costs for the required work, plus disruption of vehicle traffic and extended bypass pumping of stream flow. The cost estimate assumes 8-foot (96-inch) diameter reinforced concrete culvert, class 3, no gaskets. Cost source is RSMeans 2011, with inflation assumed at 2% per year for 3 years. The result for 2014 equals approximately 6.1%. The cost of the culvert is \$570/lf x 1.061 equals \$605/lf. Reference is RSMeans 33 41 13.60 line 2140. For a 50-foot-long culvert the cost estimate is \$30,250 for the pipe only. The cost for trenching and replacing road and embankment assumes 2 crew weeks plus a backhoe at \$300 per hour plus miscellaneous, totaling about 25K. Cost for restoring pavement and base is approximately \$200/lf, so for a 30-foot cut, the pavement and base cost is \$6K. Reference is RSMeans G2010 230 Line 3850. It is difficult to put a dollar cost on a two-week road closure, but a flat cost of \$2K is assumed.

The total estimate is then about \$30K + \$25K + \$6K + \$2K equals \$53K for construction only. Add 10% profit and 10% administration, equaling \$64K total. In addition, it is assumed that both the new and the alternative (the rehabilitated pipe as demonstrated) have a service life of 40 years, with equal maintenance; thus, the net maintenance cost is zero dollars. No periodic component replacement or refurbishment is considered because the service life exceeds the 30-year duration of the economic analysis.

Table 13 summarizes these costs.

Table 13. Cost summary for baseline case.

Baseline Case Costs	Cost (\$K)
First costs	64
Annual O&M costs	0 (net)
Periodic component replacement or refurbishment	0 (net)

4.1.2 Alternative 2 (demonstrated technology)

For the demonstrated technology, the cost of performing the rehabilitation for the four culverts at the Fort Bragg demonstration itself, with cost included in the research proposal, is \$125 per linear foot for the base contract, with \$100K additional assumed to cover MEC's costs for administration and all related support requirements, plus MEC's research and reporting efforts. Each culvert is 50 feet long, so cost is 4 each at

\$125/lf at 50 feet = \$25K. Add \$100K for MEC. The MEC rate is expected to be high by percentage of the total cost because the rehabilitation contract is small.

The cost of installing future culverts at Fort Bragg or other Army installations is assumed to be the same as described in paragraph above. For comparison, the cost of geopolymer work for future pipe rehabilitation at Fort Bragg or other installations is estimated by the contractor to be about \$500 per lf for 8-foot culverts, including both material and labor. This is not the same rate as is being used for the demonstration for reasons explained earlier that have to do with the project demonstration. Thus, a future culvert will cost \$500 to rehabilitate, because it will not need to factor the overhead associated with a research demonstration. Since the maintenance is assumed to be the same as in the baseline case, a net cost of \$0 is assumed. A summary of costs is shown in Table 14.

Table 14. Cost summary for demonstrated case of geopolymer rehabilitation.

Alternative Case Costs	Cost (\$K)
First costs	25
Annual O&M costs	0 (net)
Periodic component replacement or refurbishment	0 (net)

4.1.3 General costs and assumptions

For FY14, the demonstration work was part of and enhances a larger effort which is considered in-kind matching funding from the installation. Note that a future system of preplanned and programmed rehabilitation is necessary to realize the benefits of the geopolymer liner system technology. Such planning is necessary because if the installation reacts to collapsed pipes only, the liner system cannot be used.

The return on investment (ROI) calculation compares the baseline case to a scenario that assumes a four-year phase-in for adoption of the new technology. In the first year, the assumption is that no work was executed other than this demonstration project completed at Fort Bragg (\$495 initial investment). The rehabilitated pipe (new system) cost is zero since it is covered by the cost of the demonstration project.

For the second year of the phase-in scenario, it is assumed that there is no use of the rehabilitation product to allow for updates to specifications or recommendations. Thus, in Year 2, traditional replacement practice will be used for 10 manholes regardless of the scenario type.

For the third and fourth years, it is assumed that 5 rehabilitations will be performed by the new rehabilitation method and 5 by the old replacement method. The new system implementation cost is attributed to 5 rehabilitations x \$25K (\$125K) plus the cost of 5 replacements x \$64K (\$320K), leading to a total cost of \$445K in the third and fourth years.

For the fifth year and following years, 10 rehabilitations per year are assumed in place of any traditional replacement, with a resulting yearly rehabilitation cost of \$250K (10 x \$25K).

The investment required also includes \$5K of out-year funds that are needed to complete the required ROI reassessment report two years after the final report is published.

4.2 Projected return on investment (ROI)

The projected ROI analysis is performed in accordance with Office of Management and Budget (OMB) Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*. A 7% discount rate was used, as required. The projected ROI is 7.73 over 30 years. The calculation is based on a required CPC project investment of \$495,000, along with other assumptions explained in section 4.1.3. A summary of the ROI analysis is shown in Table 15.

Table 15. Return on investment calculation.

Return on Investment Ratio	7.73	Percent	773%
Net Present Value of Costs and Benefits/Savings	3,011,751	6,838,080	3,826,329

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1							
2	640,000		640,000		558,976	558,976	
3	320,000		125,000		102,038	261,216	159,179
4	320,000		125,000		95,363	244,128	148,766
5	640,000		250,000		178,250	456,320	278,070
6	640,000		250,000		166,575	426,432	259,857
7	640,000		250,000		155,675	398,528	242,853
8	640,000		250,000		145,500	372,480	226,980
9	640,000		250,000		135,975	348,096	212,121
10	640,000		250,000		127,075	325,312	198,237
11	640,000		250,000		118,775	304,064	185,289
12	640,000		250,000		111,000	284,160	173,160
13	640,000		250,000		103,750	265,600	161,850
14	640,000		250,000		96,950	248,192	151,242
15	640,000		250,000		90,600	231,936	141,336
16	640,000		250,000		84,675	216,768	132,093
17	640,000		250,000		79,150	202,624	123,474
18	640,000		250,000		73,975	189,376	115,401
19	640,000		250,000		69,125	176,960	107,835
20	640,000		250,000		64,600	165,376	100,776
21	640,000		250,000		60,375	154,560	94,185
22	640,000		250,000		56,425	144,448	88,023
23	640,000		250,000		52,725	134,976	82,251
24	640,000		250,000		49,275	126,144	76,869
25	640,000		250,000		46,050	117,888	71,838
26	640,000		250,000		43,050	110,208	67,158
27	640,000		250,000		40,225	102,976	62,751
28	640,000		250,000		37,600	96,256	58,656
29	640,000		250,000		35,150	89,984	54,834
30	640,000		250,000		32,850	84,096	51,246

5 Conclusions and Recommendations

5.1 Conclusions

The geopolymer spray-applied liner system is a technique with the viability and maturity to successfully repair storm-sewer culverts and other types of sewer infrastructure without diminishing its performance. Although the internal diameter is slightly reduced by the liner, the improved surface condition provides better hydraulics allowing the culvert to at least partially offset the effect on capacity. The technology should be considered as a competing product in the “no dig” industry, which also includes slip lining and CIPP. The geopolymer liner is especially useful when the diameter is 54 in. or larger. Repairing a pipe in place will often result in a large cost savings compared to removing and replacing a pipe. This rehabilitation method also results in less disruption to the installation. Installation of the liner in the 100 ft long and 4 ft wide diameter, corrugated metal pipe was simple, and it only took a few days since the material cured quickly. At the 12-month reassessment, the liner showed no significant signs of deterioration and was still performing well.

Another advantage of using a geopolymer material is the additional strength it provides, offering approximately 1.5 to 3 times greater compressive strength than typical concrete. The strength claims were validated by this study, although flexural strength tests proved lower than expected. However, the latter finding was attributed to difficulties with testing procedures.

The geopolymer mortar was also tested for acid resistance to determine the viability of its use in sanitary systems. The geopolymer deteriorated faster than PCC. ERDC-CERL’s acid test results do not agree with the manufacturer’s claims and prior test results. This result may be due to the use of a geopolymer formula containing a foaming agent that was present in the specific batch tested by ERDC-CERL. Also, the concentration of sulfuric acid used for this experiment was much more aggressive than is likely to occur in the natural environment, and the coupons were smaller than those used by the manufacturer during testing. Additionally, the samples performed better under the cyclic thin-film sulfuric acid test than the immersion test, which is a positive since the thin film condition is more likely to occur in the field. Though the manufacturer’s claims regarding acid re-

sistance were not verified, the product may still be suitable for use in sanitary sewer systems, particularly as new formulations are brought to market with better acid resistance.

5.2 Recommendations

5.2.1 Applicability

The geopolymmer liner system is a viable solution for storm and wastewater pipe rehabilitation, and should also be useful in similar structures. This technology has far-reaching utility across the DoD, as stormwater piping and related structures are common and the corrosion environment at these facilities is similar to those in non-DoD systems.

5.2.2 Implementation

DoD engineering criteria documents should be revised to allow and guide use of the demonstrated technology. At the recommendation of the U.S. Army Corps of Engineers (USACE) representative to the Civil Engineering Discipline Working Group, a new specification draft was created to include this technology, (Unified Facilities Guide Specifications) UFGS 33 01 30.71 Rehabilitation of Sewer Utilities (see full draft in Appendix D). It also is recommended this new specification be referenced in UFGS 33 40 00 Storm Drainage Utilities (see draft Criteria Change Request in Appendix D).

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Appendix A: Manufacturer's Product Information and Technical Data

The manufacturer of the demonstrated geopolymer material recommends the following standards and field testing:

- Water addition rate, pump motor speed controller setting, and pump distance
- Calculated density
- Making, curing, and sampling concrete-ASTM C31 and C172
- Compressive Strength-ASTM C39
- Slump-ASTM C143
- Temperature
- Batch water
- Dry powder GeoSpray before mixing
- Ambient air temperature within the pipe (or close to application)
- Ambient air temperature at point of mixing
- Temperature of Sampled Material- ASTM C1064

The MSDS that was current for the product at the time of the demonstration is reproduced on the following pages. Note that the product specifications and MSDS may have changed after the time of this demonstration.

Version: 1.0
Revision date: 08.29.2013

SAFETY DATA SHEET

SECTION 1: Identification of the substance/mixture and of the company/undertaking

GeoSpray™ Geopolymer Mortar

Product identifier:

Product name: GeoSpray™ Geopolymer Mortar

Relevant identified uses of the substance or mixture and uses advised against:

Identified uses:

GeoSpray is a geopolymmer cement used in the structural rehabilitation of sewer, storm and water piping, manholes and other infrastructure

Uses advised against: None

Details of the supplier of the safety data sheet:

Company identification:

Milliken Infrastructure Solutions, LLC.
1733 Majestic Drive
Suite 101
Lafayette, CO 80026 USA
(720) 921-8810 (8:00 - 17:00 M-F)
sds@milliken.com



Emergency telephone number:

Chemtrec:
1-800-424-9300 (Chemtrec - US)
1-703-527-3887 (International)

SECTION 2: Hazards identification

Classification of the substance or mixture:

The product has not been classified as hazardous according to the legislation in force.

Hazard summary:

Physical hazards: No data available.

Health hazards:

Inhalation: Crystalline silica: Overexposure to the respirable dust of crystalline silica (quartz or cristobalite, less than or equal to 5 microns in size) may lead to silicosis in humans, which is a progressive and irreversible lung disease. Dust in high concentrations may irritate the respiratory system.

Eye contact:

Dust may be irritating to the eyes and respiratory tract and may cause a low level inflammatory response in the lungs. Not known to cause permanent injury to eye tissue.

Skin contact:

Severely irritating to skin. Frequent or prolonged contact may defat and dry the skin, leading to discomfort and dermatitis. Prolonged or repeated skin contact may cause drying, cracking, or irritation.

Ingestion:

Ingestion may cause severe irritation of the mouth, the esophagus and the gastrointestinal tract.

Other Health Effects:

No data available.

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Environmental hazards: No data available.

Label elements: Not applicable

Other hazards: No data available.

SECTION 3: Composition/information on ingredients

Mixtures

General information:

Chemical name	Concentration	CAS-No.	EC No.	REACH Registration No.	Notes
Crushed stone or gravel	0 to 60 %	Not available.	Not available.	Not available.	
Sand		Not available.	Not available.	Not available.	
Portland Cement			Not available.	Not available.	
Fly Ash		Not available.	Not available.	Not available.	
Crystalline Silica		14808-60-7	Not available.	Not available.	
Proprietary Ingredients		Not available.	Not available.	Not available.	

SECTION 4: First aid measures

Description of first aid measures:

Inhalation: Dust irritates the respiratory system, and may cause coughing and difficulties in breathing. If breathing is difficult, give oxygen. Get medical attention if any discomfort continues.

Eye contact: In the event of contact with the eyes, rinse thoroughly with clean water. Continue to rinse for at least 15 minutes and seek medical attention.

Skin contact: Wash the skin immediately with soap and water. Take off immediately all contaminated clothing. If skin irritation or an allergic skin reaction develops, get medical attention.

Ingestion: If swallowed, rinse mouth with water (only if the person is conscious). Get medical attention if any discomfort continues.

Most important symptoms and effects, both acute and delayed: No data available.

Indication of any immediate medical attention and special treatment needed:

Hazards: No data available.

Treatment: No data available.

SECTION 5: Firefighting measures

General fire hazards: Firefighters must use standard protective equipment including flame retardant coat, helmet with face shield, gloves, rubber boots, and in enclosed spaces, SCBA.

Extinguishing media:

Suitable extinguishing media: Water fog. Alcohol resistant foam. Dry chemical. Carbon dioxide or dry powder.

Unsuitable extinguishing media: No data available.

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Special hazards arising from the substance or mixture: Material reacts with water.

Advice for firefighters:
Special fire fighting procedures: No data available.

SECTION 6: Accidental release measures

Personal precautions, protective equipment and emergency procedures: Wear appropriate personal protective equipment. The risk of inhalation of dust must be minimized as much as possible.

Environmental precautions: Do not release into the environment.

Methods and material for containment and cleaning up: Dam and absorb spillages with sand, earth or other non-combustible material. Ensure that waste and contaminated materials are collected and removed from the work area as soon as possible in a suitably labeled container. All waste materials should be packaged, labeled and transported in accordance with all national, state/provincial, and local requirements.

Reference to other sections: No data available.

SECTION 7: Handling and storage:

Precautions for safe handling: No specific hygiene procedures noted, but good personal hygiene practices are always advisable, especially when working with chemicals. Wash promptly with soap and water if skin becomes contaminated. Practice good housekeeping. Avoid conditions which create dust.

Conditions for safe storage, including any incompatibilities: Keep containers tightly closed. Store in a cool, dry place with adequate ventilation. Keep away from incompatible materials, open flames, and high temperatures.

Specific end use(s): No data available.

SECTION 8: Exposure controls/personal protection

Control parameters

Occupational exposure limits:

Chemical name	Type	Exposure Limit values	Source
---------------	------	-----------------------	--------

No data available.

Exposure controls

Appropriate engineering controls: No specific recommendation made, but protection against nuisance dust must be used when the general level exceeds 10 mg/m³.

Individual protection measures, such as personal protective equipment:

General information: No data available.

Eye/face protection: Wear necessary protective equipment. Avoid contact with eyes and prolonged skin contact. Chemical goggles are recommended.

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Skin protection:	
Hand protection:	Wear suitable protective clothing as protection against splashing or contamination. Wash promptly with soap and water if skin becomes contaminated. Protective gloves should be used if there is a risk of direct contact or splash. Chemical resistant gloves are recommended. If contact with forearms is likely wear gauntlet style gloves.
Other:	Wear rubber boots. Wear appropriate clothing to prevent repeated or prolonged skin contact.
Respiratory Protection:	Wear dust masks in dusty areas. If engineering controls do not maintain airborne concentrations below recommended exposure limits (where applicable) or to an acceptable level (in countries where exposure limits have not been established), an approved respirator must be worn.
Hygiene measures:	Always observe good personal hygiene measures, such as washing after handling the material and before eating, drinking, and/or smoking. Routinely wash work clothing and protective equipment to remove contaminants.
Environmental Controls:	No data available.

SECTION 9: Physical and chemical properties

Information on basic physical and chemical properties:

Appearance:

Physical State:	powder
Form:	powder
Color:	Grey
Odor:	No data available.
Odor Threshold:	No data available.
pH:	10 - 13 Aqueous suspensions
Melting point/freezing point	No data available.
Boiling Point:	No data available.
Flash Point:	No data available.
Evaporation Rate:	No data available.
Flammability (solid, gas):	No data available.
Flammability Limit - Upper (%):	No data available.
Flammability Limit - Lower (%):	No data available.
Vapor pressure:	No data available.
Vapor density (air=1):	No data available.
Relative density:	3,15
Solubility(ies):	
Solubility in Water:	No data available.
Solubility (other):	No data available.
Partition coefficient (n-octanol/water):	No data available.
Autoignition Temperature:	No data available.
Decomposition Temperature:	No data available.
Viscosity:	No data available.
Explosive properties:	No data available.
Oxidizing properties:	No data available.
Other information	
No data available.	

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SECTION 10: Stability and reactivity

Reactivity:	Material is stable under normal conditions.
Chemical stability:	No data available.
Possibility of hazardous reactions:	The product reacts with water and will generate heat.
Conditions to avoid:	No data available.
Incompatible materials:	No data available.
Hazardous decomposition products:	No data available.

SECTION 11: Toxicological information

Information on likely routes of exposure

Inhalation:	No data available.
Ingestion:	No data available.
Skin contact:	No data available.
Eye contact:	No data available.

Information on toxicological effects:

Acute Toxicity:

Oral:	
Product:	No data available.

Dermal:	
Product:	No data available.

Inhalation:	
Product:	No data available.

Repeated dose toxicity:	
Product:	No data available.

Skin corrosion/irritation:	
Product:	No data available.

Serious eye damage/eye irritation:	
Product:	No data available.

Respiratory or skin sensitization:	
Product:	No data available.

Germ cell mutagenicity:

In vitro:	
Product:	No data available.

In vivo:	
Product:	No data available.

Carcinogenicity:	
Product:	No data available.

Version: 1.0
Revision date: 08.29.2013

Reproductive toxicity:
Product: No data available.

Specific target organ toxicity - single exposure:
Product: No data available.

Specific target organ toxicity - repeated exposure:
Product: No data available.

Aspiration hazard:
Product: No data available.

Other adverse effects: None

SECTION 12: Ecological information

Toxicity

Acute toxicity

Fish:
Product: No data available.

Aquatic invertebrates:
Product: No data available.

Chronic Toxicity:

Fish:
Product: No data available.

Aquatic invertebrates:
Product: No data available.

Toxicity to Aquatic Plants:
Product: No data available.

Persistence and degradability:

Biodegradation:
Product: No data available.

BOD/COD ratio:
Product: No data available.

Bioaccumulative potential:

Product: No data available.

Mobility in soil:

Results of PBT and vPvB assessment: No data available.

Other adverse effects: No data available.

SECTION 13: Disposal considerations

Waste treatment methods

General information: No data available.

Disposal methods
EU SDS

Version: 1.0
Revision date: 08.29.2013

Product: Dispose of waste at an appropriate treatment and disposal facility in accordance with applicable laws and regulations, and product characteristics at time of disposal.

Contaminated packaging: No data available.

European Waste Codes: None

SECTION 14: Transport information

Land (ADR/RID)

Not regulated.

Sea (IMDG)

Not regulated.

Air (ICAO/IATA)

Not regulated.

Environmental hazards: Not regulated.

Special precautions for user: No special precautions.

Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code: Not applicable.

SECTION 15: Regulatory information

Safety, health and environmental regulations/legislation specific for the substance or mixture

Ready mix concrete/cement/geopolymer is considered a hazardous chemical under USDOL-OSHA Hazard Communication Rule, 29 CFR 1910.1200 and should be part of any hazard communication program.

Ready mix concrete/cement/geopolymer qualifies as a hazardous substance with delayed health effects under SARA (Title III), Sections 311 and 312.

Some substances in Ready Mix Concrete/cement/geopolymer are on the TSCA inventory list.

Ready mix concrete/cement/geopolymer is a hazardous substance under the Federal Hazardous Substance Act (USA)

Under California Proposition 65, this product contains chemicals (trace metals) known to the State of California to cause cancer, birth defects, or other reproductive harm. California law requires the manufacturer to give the above warning in the absence of definitive testing to prove the defined risks do not exist.

Portland cement is considered to be a hazardous material under the Hazardous Products Act as defined by the Controlled Products Regulations and is therefore subject to the labeling and MSDS requirements of the Workplace Hazardous Materials Information System (WHMIS)

This product has been classified in accordance with the hazard criteria of the CPR and the SDS contains all the information required by the CPR.

Chemical safety assessment: No data available.

SECTION 16: Other information

Revision Information: Not relevant.

Key literature references and sources for data: No data available.

EU SDS

Milliken®
GeoSpray™
 Geopolymer Mortar

Technical Data Sheet
 Version - April, 2015

GeoSpray™ geopolymer is a high performance fiber reinforced mortar specifically designed for structural rehabilitation. This high strength, ultra-low porosity material is made from natural mineral polymers and recycled industrial waste streams. GeoSpray is designed for use through multiple application techniques including pouring, placing, trowelling, spraying, or centrifugal casting.

GeoSpray can be used for rehabilitation of pipes and structures in Civil Infrastructure, Gas & Oil and Chemical industries. In addition, it is used to repair tunnels, bridges, and roads as well as to rehabilitate buildings and containment areas.



Test Method	Duration	GeoSpray	Conventional Repair Mortar
Compressive Strength ASTM C-39/C-109	1 Day 28 Days	Min. 2,500 psi / 17 MPa Min. 8,000 psi / 55 MPa	5000 psi / 34 MPa
Flexural Strength ASTM C-78	7 Day 28 Days	900 psi / 6.2 MPa 1300 psi / 9 MPa	500 psi / 3.4 MPa
Modulus of Elasticity ASTM C-469	1 Day 28 Days	3,000,000 psi / 20700 MPa 5,800,000 psi / 40000 MPa	3,000,000 psi / 20700 MPa
Bond Strength to Concrete ASTM C-882	1 Day 28 Days	Min 1,300 psi / 9 MPa Min. 2,500psi / 11 MPa	N/A
Set Time ASTM C-807	Initial Set	60 - 75 Minutes	120 Minutes
Initial Cure Time	Final Set	90 - 110 Minutes	300 minutes
Freeze Thaw Durability ASTM C-666	300 Cycles	100% Zero loss	80% to 90% 10% to 20% degradation
Shrinkage ASTM C-1090	28 Days	0.00% @ 65% R. H.	0.35% to 0.50% Shrinkage
Tensile Strength ASTM C-496	28 Days	Min. 800 psi / 5.5 MPa	400 psi / 2.7 MPa
Abrasion Resistance ASTM C-1138	6 Cycles @ 28 Day Maturity	0.67% Loss	5.60% Loss
Rapid Chloride Ion Permeability ASTM C-1202	28 Days	Very Low	N/A

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Composition

A proprietary micro-fiber reinforced ultra - dense geopolymers mortar designed for mechanical pumping and spraying. GeoSpray is an inorganic polymeric system that adheres strongly to prepared cement surfaces and itself.

Characteristics

A dark grey mortar with near-zero porosity. Wet density of ~127 lbs/ft³, or 2035 kg/m³.

Largest particle size: 0.3 mm.

Yield and Coverage

Yields 0.43 ft³ (0.012 m³) per 50 lbs. For one 50lb bag, coverage is 10.3 ft² at 0.5" depth (0.96m² per 12mm depth)

Packaging

GeoSpray is available in 50lb (22.7kg) sealed bags or in 2,000lb (908kg) super sacks.

Cleaning and Preparation

The surface shall be thoroughly cleaned. Use high-pressure water blasting with a minimum of 3500 psi (or as required by local provisions) to clean and free all foreign material, including dirt, grit, roots, grease, sludge or other material that may be attached to the existing surface. All loose or defective brick, grout, or surface irregularities should be removed to provide an even surface prior to application of GeoSpray. When grease and oil are present, an approved detergent or muriatic acid shall be used integrally with the high pressure cleaning water. All materials resulting from the cleaning of the pipe shall be removed prior to application of GeoSpray.

Mixing

Do not exceed a 0.20 w/c ratio. Always add GeoSpray to the water. Follow normal industry standards for batching and mixing.

Work Time

Work time is 60 - 90 minutes at 80°F (27°C).

Application

Once mixed to proper consistency and homogeneity, GeoSpray can be hand troweled as a repair mortar for crack repair prior to spraying.

GeoSpray should be pumped from a horizontal mix auger cavity via an adjustable rotor stator pump through a hose for delivery to the appropriate application device (spray nozzle or spinner head), and shall be applied to a damp surface.

GeoSpray has an ultra-low abrasion rate on hoses and equipment; they will last much longer, with fewer interruptions and remobilizations.

Finishing

If necessary, troweling of materials can begin following the spray application. Initial troweling shall be in an upward motion, to compress the material into voids and solidify the pipe wall. Take precautions not to over trowel.

GeoSpray can be finished using a steel trowel, wood float, sponge float, broom or brush, depending on the surface texture desired. Do not use a magnesium float.

Curing

Optimum curing occurs in a moist and moderate environment. General underground conditions are usually adequate to meet this requirement. If dry and/or hot conditions are present, the use of a wind barrier and fogging spray will be required.

During hot weather conditions, chilled water may be used to mix GeoSpray geopolymers. GeoSpray geopolymers cement should be maintained at a temperature lower than 90°F (32°C). Standard industry practices may be used to maintain proper temperature. Alternatively, GeoSpray should not be placed when the temperature in the curing environment is below 37°F (3°C). During cold weather conditions, heaters, thermal breaks, and other methods may be used to maintain temperature above that threshold.

Storage & Handling

GeoSpray shall be stored in a cool, dry location. Stored under proper conditions, shelf life is one year.

Quality Control & Material Testing

For each section length designated by the owner in the contract documents or purchase order, GeoSpray will be collected at the end of the hose near the discharge point. Use 4" by 8" cylinders in accordance with Test Method ASTM C 39/39M or sprayed panels in accordance with ASTM C1140.

Health & Safety

GeoSpray is a cementitious powder, is alkaline and may cause significant skin and eye irritation. Adequate health and safety precautions should be observed during all storage, handling, use and drying periods. For safety and health precautions, reference the current version of the Safety Data Sheet for GeoSpray. When using GeoSpray in a confined space or closed area, consult the current OSHA or ANSI bulletins on safety requirements. Do not take internally. If swallowed, call a physician immediately.

Warranty

Milliken Infrastructure Solutions, LLC warrants this product to be free of defects in material and manufacturing. Should the product prove to be defective, the liability to Milliken Infrastructure Solutions shall be limited to replacement of the product, ex-factory. Milliken Infrastructure Solutions makes no warranties as to merchantability or fitness for a particular purpose. This warranty is in lieu of all other warranties expressed or implied. Users should determine the suitability of the product for the intended use and assume all risk and liability in connection therewith.



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Milliken Infrastructure Solutions, LLC

Appendix B: Quality Assurance and Quality Control Supporting Documentation for Geopolymer



On-Site Quality Assurance and Quality Control Procedures

EXECUTIVE SUMMARY

This document outlines the standard manufactures recommend proceeds for testing GeoSpray™ material applications. Any deviation from these recommendations should be approved by the supplier in writing.

Disclaimer: Please Note: As each customer's use of our product may be different, information we provide, including without limitation, recommendations, test results, samples, care/labeling/processing instructions or marketing advice, is provided in good faith but without warranty and without accepting any responsibility/liability. Each customer must test and be responsible for its own specific use, further processing, labeling, marketing, etc. All sales are exclusively subject to our standard terms of sale posted at www.milliken.com/terms (all additional/different terms are rejected) unless explicitly agreed otherwise in a signed writing.

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GeoPolymer On-Site Quality Assurance and Quality Control Procedures
Mortar Solutions

In order to help insure that the geopolymer materials are properly mixed and prepared to specification on-site at a specific project it is standard in the construction industry to have a 3rd party certified lab collect and test material directly from the on-site mixing equipment.

The materials must be tested in accordance with ASTM (or appropriate local standards depending on the country of use) along with Milliken Infrastructure Solutions, LLC (MIS) specifications and the procedures detailed in the document. Test must be performed by American Concrete Institute (ACI) accredited technicians (or appropriate local certified technicians depending upon the country of use) and in a certified third party independent laboratory. MIS recommends using third party independent testing agencies with ACI certified technicians to collect, cast, transport, cure and test.

Third party labs can be identified by using the AASHTO Materials Reference Laboratory list in the United States by using the laboratory search function available at www.amrl.net

Minimum tests or measurements to be performed:

- Water Addition Rate, Pump Motor Speed Controller Setting & Pump Distance
- Calculated Density
- Compressive Strength
- Slump
- Temperature
 - 1. Batch Water
 - 2. Dry Powder GeoSpray before mixing
 - 3. Ambient Air Temperature within the pipe (or close to application)
 - 4. Ambient Air Temperature at point of mixing
 - 5. Temperature of Sampled Material

Frequency of Testing and Sampling:

The above testing is to be initiated on-site and during placement of GeoSpray. At minimum a complete series of tests should be performed with every 10 cubic yards or 32,000 pounds (~14,500 kg) of material placed. In addition to the minimum required series of testing based on material quantities, the following testing frequency is required:

- The 1st day GeoSpray is placed or applied at a project site.
- At minimum every other day GeoSpray is placed or applied at a project site.
- The final day GeoSpray is placed or applied at the project site.

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Reference Standards and Documents:

- ASTM C-31: Standard Practice for Making & Curing Concrete Test Specimens in the Field.
- ASTM C-39/C-39M: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.
- ASTM C-125: Standard Terminology Relating to Concrete and Concrete Aggregates
- ASTM C-143/C-143M: Standard Test Method for Slump of Hydraulic-Cement Concrete.
- ASTM C-172: Standard Practice for Sampling Freshly Mixed Concrete.
- ASTM C-1064/C-1064M: Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete.
- ACI CP-1(14): Technical Workbook for ACI Certification of Concrete Field Testing Technician-Grade 1.
- ACI 309R: Guide for Consolidation of Concrete.

Terminology:

For all definitions of terms used in this document related to the mixing, sampling, curing, storing and testing of geopolymer, concrete, hydraulic-cements or related cementitious materials please refer to ASTM C-125.

Sampling:

ASTM C-172 should be consulted prior to any sampling of GeoSpray in the field. In addition to the procedures outline in ASTM C-172, the following additional procedures, precautions or requirements should be observed with respect to sampling of GeoSpray:

- Sample size to be used for strength tests requires a minimum of 28 L (1 ft³)
- GeoSpray sample should be collected at the end of the hose near the discharge point. Only in rare circumstances where this may not be possible, a sample may be drawn from a section of hose at minimum 50 feet from the mixer/pump. All samples points and approximate distance from the mixer pump must be noted. In the event the certified technician does not have access to the sampling point (specifically for safety of technician and related confined space regulations), samples should be drawn by the contractor responsible for the placement of the material and *IMMEDIATELY* transferred to the nearest access point to allow the chain of custody to be transferred to the certified technician for testing.

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Water Addition Rate, Pump Motor Speed Controller Setting & Pump Distance:

It is necessary for the certified technician to verify and record the mixer and pump setting that were in use at the time of sampling. The technician should physically verify and record these settings. In the rare occurrence that the mixing and pump equipment is not accessible to the technician, the operating contractor should provide digital pictures taken at the time of sampling (date and times stamped if possible) of the settings to the technician for his/her records.

The following procedures, precautions or requirements should be observed with respect to this activity:

- Determine, verify and record current water addition setting from the Mixer/Pump at the time of sampling. Flow Meter sight gauges are generally located on the control side of the equipment. Reading generally range between 150 and 200.
- Determine, verify and record current Pump Motor Speed Setting at the time of sampling. Pump motor speed control is located on the control side of the Mixer/Pump in general. Examples generally range between 1 and 10.
- Determine, verify and record the distance between the pump and sampling point. Note if this is different than the distance between the pump and the spinner head.

Casting of Specimens:

ASTM C-31 should be consulted prior to casting samples of GeoSpray in the field. In addition to the procedures outlined in ASTM C-31, the following additional procedures, precautions or requirements should be observed with respect to casting of GeoSpray:

- For compression testing use *ONLY* 4 inch x 8 inch cylinders (or the metric equivalent).
- A *MINIMUM* of six cylinders are to be cast with each test. 2 cylinders will be broken at 7 days of aging, 3 at 28 days of aging, and 1 will be broken at 56 days of aging or as directed.
- Molding: Mold specimens promptly on a level, ridged surface, *FREE* of vibration and other disturbance, at a place as near as practical to the location where they are to be stored.
- Cylinders must be *IMMEDIATELY* capped with a water tight sealing cap provided with the molds.
- Storage: *IMMEDIATELY* after molding the specimens they should be stored for a period of at least 48 hrs in a temperature range between 68 and 78°F.
- Curing: GeoSpray requires final cure be in a 50% Relative Humidity room or chamber. In situations where a 50% RH room is not available, cylinders may be stripped and wrapped in a wet burlap and placed in a temperature controlled room. Wet burlap should be kept moist throughout cure. In all cases *DO NOT SUBMERGE GEOSPRAY SAMPLES IN LIQUID CURE TANK OR IN WATER*.

Calculated Density:

ASTM C-39/C-39M should be consulted prior to casting or testing samples of GeoSpray for calculated density. In addition to the procedures outlined in ASTM C-39/C-39M, the following additional procedures, precautions or requirements should be observed with respect to calculation of density for GeoSpray:

- Measure, weigh, record and calculate the density of the 4 inch x 8 inch cylinders prior to compression testing.

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Compressive Strength:

ASTM C-39/C-39M should be consulted prior to casting or testing samples of GeoSpray for compressive strength. In addition to the procedures outline in ASTM C-39/C-39M, the following additional procedures, precautions or requirements should be observed with respect to compression testing of GeoSpray:

- For compression testing use *ONLY* 4 inch x 8 inch cylinders (or the metric equivalent).
- Curing: GeoSpray requires final cure be in a 50% Relative Humidity room or chamber. In situations where a 50% RH room is not available, cylinders may be stripped and wrapped in a wet burlap and placed in a temperature controlled room. Wet burlap should be kept moist throughout cure. In all cases *DO NOT SUBMERGE GEOSPRAY SAMPLES IN LIQUID CURE TANK OR WATER.*

Slump:

ASTM C-143/C-143M should be consulted prior to testing samples of GeoSpray for slump. In addition to the procedures outline in ASTM C-143/C-143M, the following additional procedures, precautions or requirements should be observed with respect to slump testing of GeoSpray:

- GeoSpray sample should be collected at the end of the hose near the discharge point. Only in rare circumstances where this may not be possible, a sample may be drawn from a section of hose at minimum 50 feet from the mixer/pump. All samples points and approximate distance from the mixer pump must be noted. In the event the certified technician does not have access to the sampling point (specifically for safety of technician and related confined space regulations), samples should be drawn by the contractor responsible for the placement of the material and *IMMEDIATELY* transferred to the nearest access point to allow the chain of custody to be transferred to the certified technician for testing.

Temperature:

ASTM C-1064/C-1064M should be consulted prior to temperature measurement of GeoSpray, air and water. In addition to the procedures outline in ASTM C-39/C-39M, the following additional procedures, precautions or requirements should be observed with respect to temperature measurement:

- Batch water: Pull a sample of the batch water from the “cleaning Tap” located on the opposite side of the controls of the mixer/pump. Place sample in a cup or vessel and measure and record water temperature.
- Dry powder GeoSpray before mixing: Draw a sample of GeoSpray powder from material feed point. Take temperature and record.
- Ambient air with the pipe (or close to application site): Measure and record.
- Ambient air at point of mixing: Measure and record.
- Mixed wet GeoSpray: Place sample in an approved vessel, measure and record.
- In the event that the pump, mixer, application site or feed site are not accessible to the certified technician due to safety or logistical concerns, readings may be taken by contractor personnel and communicated to the certified technician.

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Reporting:

The following information must be verified, recorded and contained in the following certified technician's report:

- Names of certified technicians collecting samples or performing measurements.
- Location of job site and project identification.
- Date and time of sample collection.
- Results of slump, temperatures, water addition rate, pump motor speed setting, pump distance and any other field tests performed.
- Explanations of any deviations from referenced standard test methods.
- Date and time samples were received at the certified lab or storage facility.
- Curing methods - including initial curing method with maximum and minimum temperatures and final curing methods and conditions.
- Compressive results with data and calculations
- Density results with data and calculations.

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Appendix C: Documentation of Additional Results

C.1. Third-party field data results

This section contains strength test results of the geopolymer cylinders by the third-party tester, ECS Carolinas LLP of Fayetteville, NC.*

 <p>ECS Carolinas, LLP 726 Ramsey Street Suite 3 Fayetteville, NC 28301 (910) 401-3288 [Phone] (910) 323-0539 [Fax] NC Registered Engineering Firm # F-1078</p>	<p>CONCRETE, GROUT, AND MORTAR TESTS LETTER OF TRANSMITTAL</p>				
<p>TO: IPR Southeast 5207 Brer Rabbit Rd. Stone Mountain, GA 30083 ATTN: [REDACTED] JOB NO.: 003119</p>	<p>DATE: 01/11/2015 RE: Simmons AA Concrete Testing PERMIT #: [REDACTED]</p>				
<p>LOCATION: Parham Blvd, Fayetteville, NC Cumberland County</p>					
<p>We are enclosing:</p> <table border="0"><tr><td><input checked="" type="checkbox"/> Attached</td><td><input checked="" type="checkbox"/> For Your Use</td></tr><tr><td><input checked="" type="checkbox"/> Materials Engineering Division Concrete Reports: 1, 2, 3</td><td><input checked="" type="checkbox"/> As Requested</td></tr></table>		<input checked="" type="checkbox"/> Attached	<input checked="" type="checkbox"/> For Your Use	<input checked="" type="checkbox"/> Materials Engineering Division Concrete Reports: 1, 2, 3	<input checked="" type="checkbox"/> As Requested
<input checked="" type="checkbox"/> Attached	<input checked="" type="checkbox"/> For Your Use				
<input checked="" type="checkbox"/> Materials Engineering Division Concrete Reports: 1, 2, 3	<input checked="" type="checkbox"/> As Requested				
<p>CC: [REDACTED]</p>					
<p>By: [REDACTED]</p>					

This report (and any included attachments) shall not be reproduced, except in full, without the prior written approval of ECS.

* Names and signatures have been redacted to maintain individuals' privacy.



ECS Carolinas, LLP
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 Fayetteville, NC 28301
 (910) 401-3288 [Phone]
 (910) 323-0539 [Fax]

Project: Simmons AA Concrete Testing
 Location: Parham Blvd, Fayetteville, NC

Concrete Cylinders Strength Report

Project : 3119 Set Designation: A
 Cast Date: 12/12/2014
 Design Strength: 10000 psi
 Report No. [REDACTED] 3

Owner: IPR Southeast - kurt Johnston
 Arch.: IPR Southeast - kurt Johnston
 Struc. Eng.: Conc. Contr.:

Placement Location: Storm Drain

Concrete Supplier:	Mixed On-Site	Truck No:	1	Ticket No:	1
Mix Designation:	Geo Spray	Mix Strength:	10000 psi	Batch Time:	10:15AM
Added Water:	0				

FIELD TEST DATA:	Tested by: Donny Johnson	Time Sampled: 10:16AM	Slump: 5.00 in.
	Temperature - Air: 50° F	Concrete: 60° F	Air Content:

Sample No	Test Date	Test Age	Type Cure	Average Measured Diameter in.	Avg. Measured Cross-Sectional Area in.-sq	Breaking Load,lbs	Compr. Str.,psi	Brk Typ	Review by
48875	12/19/2014	7	Lab	4.00	12.56	94335	7510	2	MAC3
48876	12/19/2014	7	Lab	4.00	12.56	94045	7480	2	MAC3
48877	01/09/2015	28	Lab	4.00	12.56	143945	11450	2	MAC3
48878	01/09/2015	28	Lab	4.00	12.56	135910	10820	2	MAC3
48879	01/09/2015	28	Lab	4.00	12.56	138610	11030	2	MAC3
48880	01/09/2015	28	Lab	4.00	12.56	141130	11230	2	MAC3
48881	02/06/2015	56	Lab						

Sampling in accordance with (aw) ASTM C172, except that samples may have been taken from the beginning of the load after a minimum discharge of approximately one cubic yard. Cylinder molding and laboratory curing law ASTM C31, compressive strength test and break type law ASTM C39, slump law C143, air content law ASTM C173 (V) or C231 (P), temperature law ASTM C1064, and unit weight law ASTM C138. Cylinders are tested using unbonded caps law ASTM C1231 or bonded caps law C617. Break Types are classified as: Type 1, 2, 3, 4, 5, or 6 law C39.

FIELD CURING CONDITIONS:

Curing Box
 No Curing Box

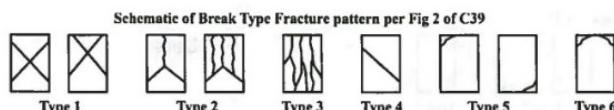
Insulated
 Heated

Cooled
 Caps

Ice
 Other

Remarks:

Final Review By:



MAC3

Print Date:

01/11/2015

BR01



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(910) 401-3288 [Phone]
(910) 323-0539 [Fax]

Project: Simmons AA Concrete Testing
Location: Parham Blvd, Fayetteville, NC

Concrete Cylinders Strength Report

Project : 3119 Set Designation: A
Cast Date: 12/11/2014
Design Strength: 10000 psi
Report No.: 2

Owner:	Client:	IPR Southeast -
Arch.:	Gen. Contr.:	IPR Southeast -
Struc. Eng.:	Conc. Contr.:	

Placement Location: Storm drain piping

Concrete Supplier:	Mixed On-Site	Truck No:	1	Ticket No:	1
Mix Designation:	Geo Spray	Mix Strength:	10000 psi	Batch Time:	10:30AM
Added Water:	0				

FIELD TEST DATA:	Tested by: Donny Johnson	Time Sampled: 10:31AM	Slump: 7.00 in.
	Temperature - Air: 45° F	Concrete: 56° F	Air Content:

Sample No	Test Date	Test Age	Type Cure	Average Measured Diameter in.	Avg. Measured Cross-Sectional Area in.-sq	Breaking Load, lbs	Compr. Str., psi	Brk Typ	Review by
48809	12/18/2014	7	Lab	4.00	12.56	89300	7110	2	MAC3
48810	12/18/2014	7	Lab	4.00	12.56	90305	7190	2	MAC3
48811	01/08/2015	28	Lab	4.00	12.56	128055	10190	2	MAC3
48812	01/08/2015	28	Lab	4.00	12.56	127420	10140	2	MAC3
48813	01/08/2015	28	Lab	4.00	12.56	128840	10250	2	MAC3
48814	02/05/2015	56	Lab						
48815	01/08/2015	28	Lab						

Sampling in accordance with (law) ASTM C172, except that samples may have been taken from the beginning of the load after a minimum discharge of approximately one cubic yard. Cylinder molding and laboratory curing law ASTM C31, compressive strength test and break type law ASTM C39, slump law C143, air content law ASTM C173 (V) or C231 (P), temperature law ASTM C1064, and unit weight law ASTM C138. Cylinders are tested using unbonded caps law ASTM C1231 or bonded caps law C617. Break Types are classified as: Type 1, 2, 3, 4, 5, or 6 law C39.

FIELD CURING CONDITIONS:

Curing Box
No Curing Box

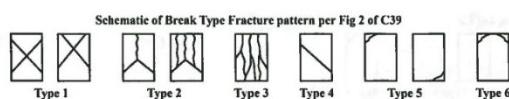
Insulated
Heated

Cooled
Caps

Ice
Other

Remarks:

Final Review By:



MAC3

Print Date: 01/11/2015

BR01



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(910) 323-0539 [Fax]

Project: Simmons AA Concrete Testing
Location: Parham Blvd, Fayetteville, NC

Concrete Cylinders Strength Report

Project: 3119 Set Designation: A
Cast Date: 12/10/2014
Design Strength: 10000 psi
Report No.: 1

Owner:	Client:	IPR Southeast
Arch.:	Gen. Contr.:	IPR Southeast
Struc. Eng.:	Conc. Contr.:	

Placement Location: Storm drain piping

Concrete Supplier:	Mixed On-Site	Truck No:	1	Ticket No:	1
Mix Designation:	Geo Spray	Mix Strength:	10000 psi	Batch Time:	11:30AM
Added Water:	0				

FIELD TEST DATA:	Tested by: Donny Johnson	Time Sampled: 11:31AM	Slump: 7.50 in.
	Temperature - Air: 55° F	Concrete: 62° F	Air Content:

Sample No	Test Date	Test Age	Type Cure	Average Measured Cross-Sectional Area in.-sq	Breaking Load,lbs	Compr. Str.,psi	Brk Typ	Review by
48802	12/17/2014	7	Lab	4.00	12.56	81680	6500	2 MAC3
48803	12/17/2014	7	Lab	4.00	12.56	80425	6400	2 MAC3
48804	01/07/2015	28	Lab	4.00	12.56	125935	10020	2 MAC3
48805	01/07/2015	28	Lab	4.00	12.56	126900	10100	2 MAC3
48806	01/07/2015	28	Lab	4.00	12.56	126220	10040	2 MAC3
48807	02/04/2015	56	Lab					

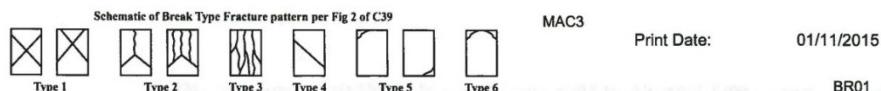
Sampling in accordance with law ASTM C172, except that samples may have been taken from the beginning of the load after a minimum discharge of approximately one cubic yard. Cylinder molding and laboratory curing law ASTM C31, compressive strength test and break type law ASTM C39, slump law C143, air content law ASTM C173 (V) or C231 (P), temperature law ASTM C1064, and unit weight law ASTM C138. Cylinders are tested using unbonded caps law ASTM C1231 or bonded caps law C617. Break Types are classified as: Type 1, 2, 3, 4, 5, or 6 law C39.

FIELD CURING CONDITIONS:

<input checked="" type="checkbox"/> Curing Box	<input checked="" type="checkbox"/> Insulated	Cooled	Ice
No Curing Box	Heated	X Caps	Other

Remarks:

Final Review By:



C.2. Photos of various test results

Photos in this section were taken by researchers at ERDC-CERL for purposes of showing: field samples from cyclic sulfuric acid trials (Table C1, C2 and C3), field samples of sulfuric acid immersion trials (Table C4 and C5), SEM results (Table C6), EDS data (Tables C7 and C8), and observed cracking in test project (Table C9).

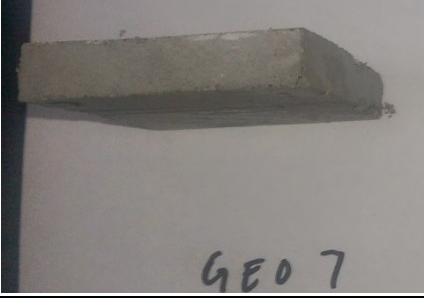
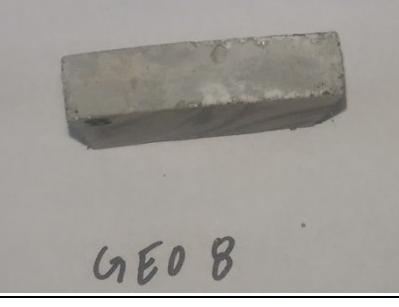
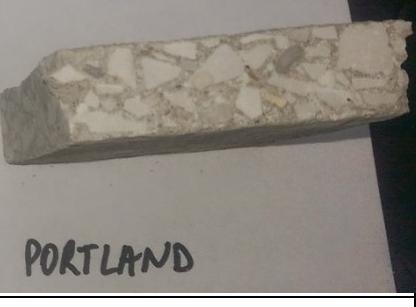
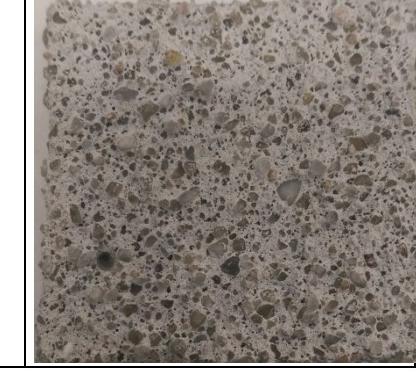
Table C1. Field samples–cyclic sulfuric acid test, Trial 1.

Portland Concrete	Geopolymer 2	Geopolymer 3
<i>Initial photos</i>		
		
		
<i>End of Week 1</i>		
		

Table C1 (continued). Field samples–cyclic sulfuric acid test, Trial 1.

<i>End of Week 2</i>		
		
<i>End of Week 3</i>		
		
		

Table C2. Field samples—cyclic sulfuric acid test, Trial 2.

Portland Concrete	Geopolymer 7	Geopolymer 8
<i>Initial photos</i>		
		
		
<i>GEO 7 GEO 8 PORTLAND</i>		
<i>End of Week 1</i>		
		

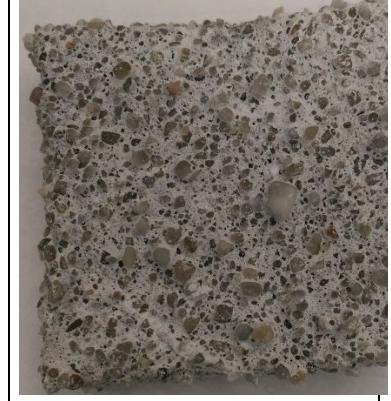
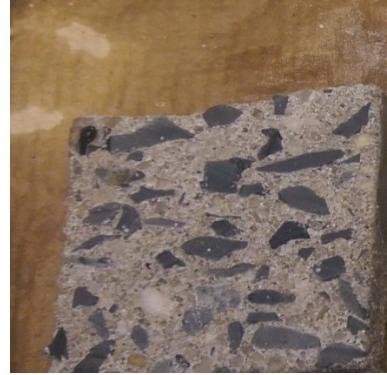
Portland Concrete	Geopolymer 7	Geopolymer 8
Table C2 (continued). Field samples–cyclic sulfuric acid test, Trial 2.		
End of Week 2		
		
End of Week 3		
		
 GEO 7 GEO 8 PORTLAND		

Table C3. Manufacturer's samples—cyclic sulfuric acid test, Trial 3.

Portland Concrete	Geopolymer 1	Geopolymer 2
<i>Initial Pictures</i>		
		
<i>End of Week 1</i>		
		
<i>End of Week 2</i>		
		

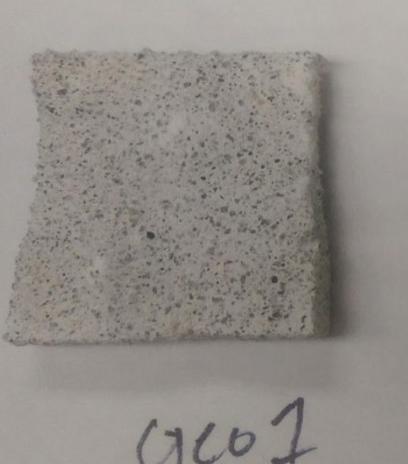
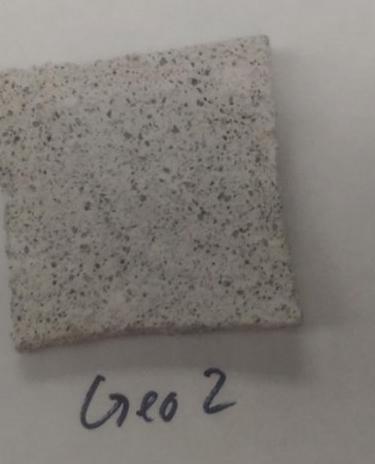
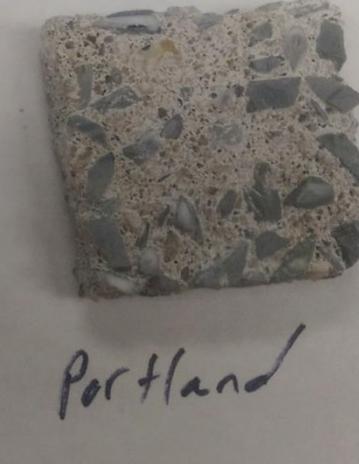
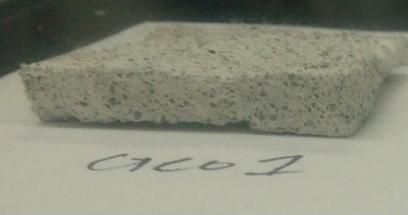
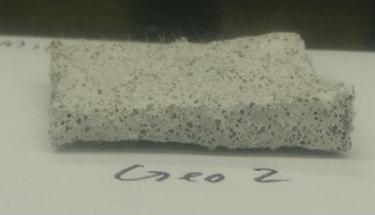
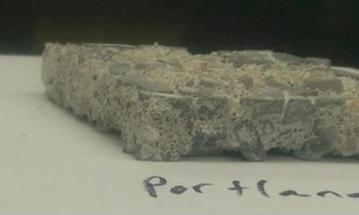
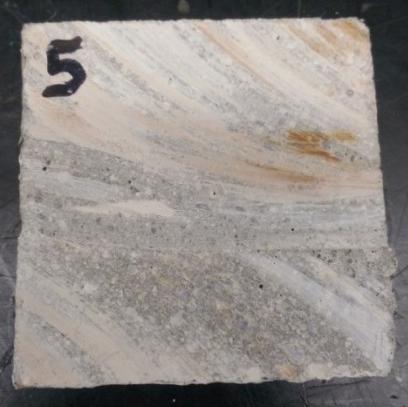
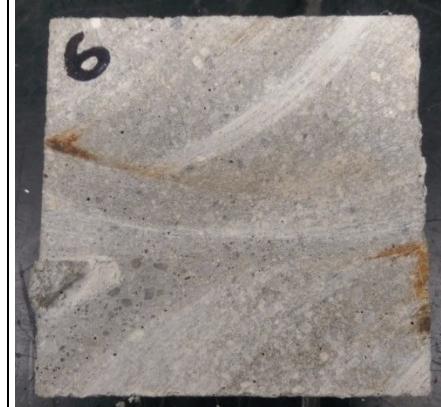
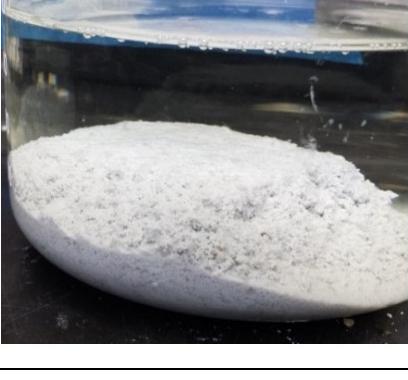
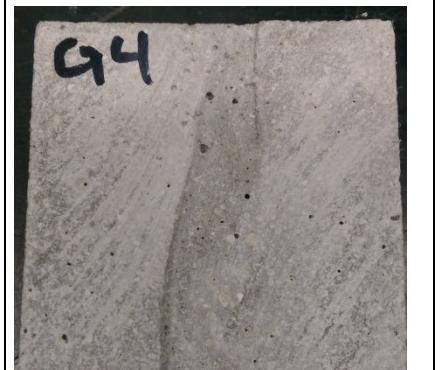
Portland Concrete	Geopolymer 1	Geopolymer 2
Table C3 (cont'd). Field samples—cyclic sulfuric acid test, Trial 3 (manufacturer's samples).		
End of Week 3		
		
		
Geo 1	Geo 2	Portland
		
Geo 1	Geo 2	Portland

Table C4. Field samples–sulfuric acid immersion test, Trial 1.

Portland Concrete	Geopolymer 5	Geopolymer 6
<i>Initial Pictures</i>		
		
<i>End of Week 1</i>		
		
<i>End of Week 2</i>		
		

Portland Concrete	Geopolymer 5	Geopolymer 6
Table C4 (continued)–sulfuric acid immersion test, Trial 1.		
<i>End of Week 3</i>		
		
<i>Final Pictures</i>		
		

**Table C5. Field samples–sulfuric acid immersion test, Trial 2
(manufacturer's samples).**

Portland Concrete	Geopolymer 3	Geopolymer 4
<i>Initial Pictures</i>		
		
<i>End of Week 1</i>		
		
<i>End of Week 2</i>		
		

Portland Concrete	Geopolymer 3	Geopolymer 4
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Table C5 (continued). Field Samples–sulfuric acid immersion test, Trial 2 (manufacturer's samples).

End of Week 3		
		
Final Pictures		
		
Note that in the above photo, no solid material remained.		

Table C6. Photos of SEM results, Trials 2 and 3.

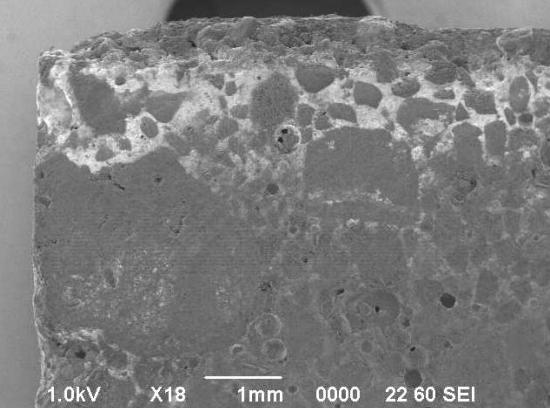
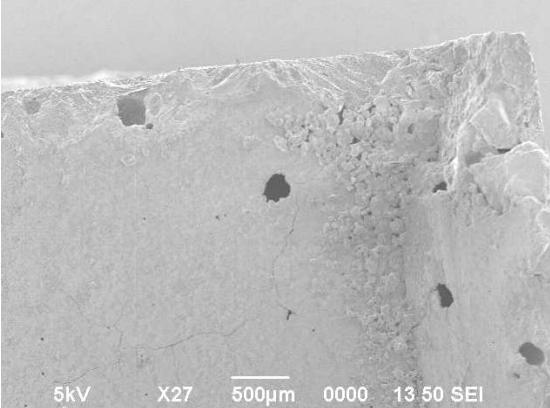
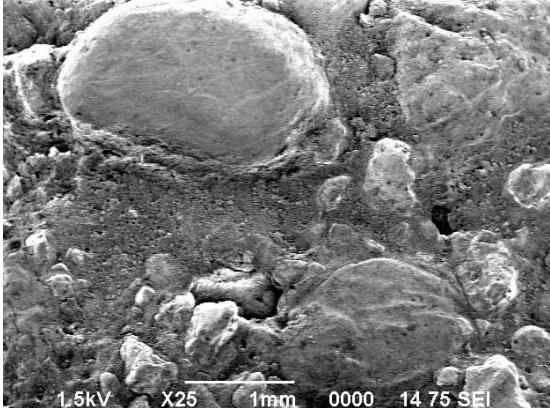
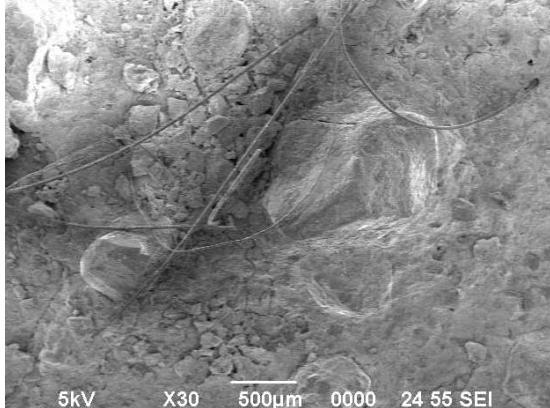
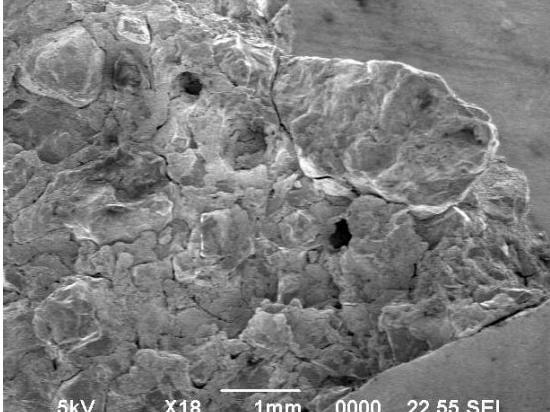
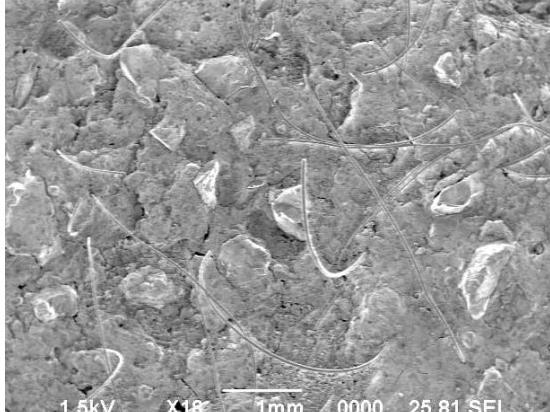
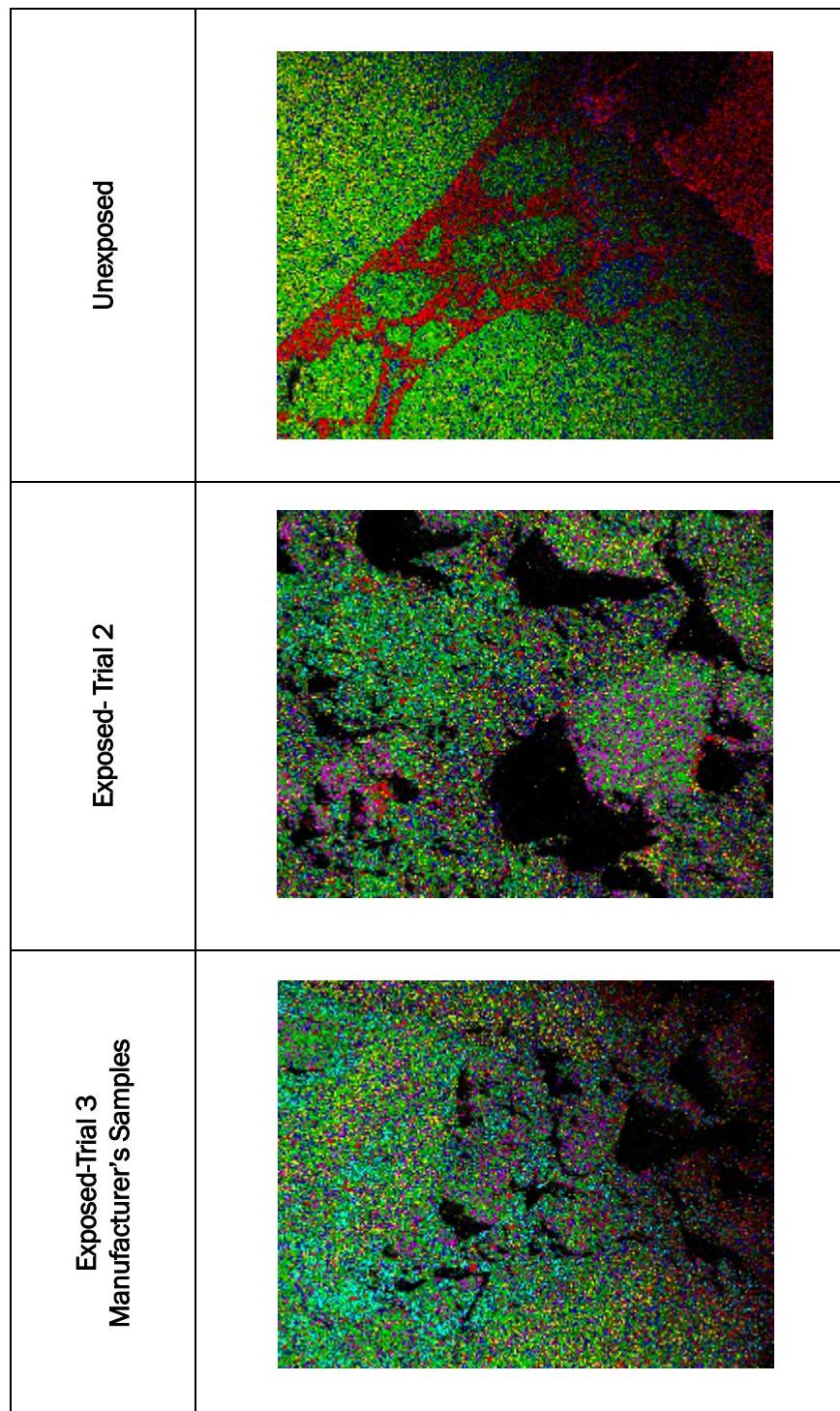
	Portland	Geopolymer Concrete
Unexposed sample		
Exposed-Trial 2		
Exposed-Trial 3 Manufacturer's Samples		

Table C7. EDS data for regular concrete- Trials 2 and 3.



*Sulfur content was not observed in the unexposed sample. It is displayed as cyan in the exposed samples, demonstrating the exposure to sulfur did alter the surface.

Table C8. Geopolymer EDS data, Trials 2 and 3.

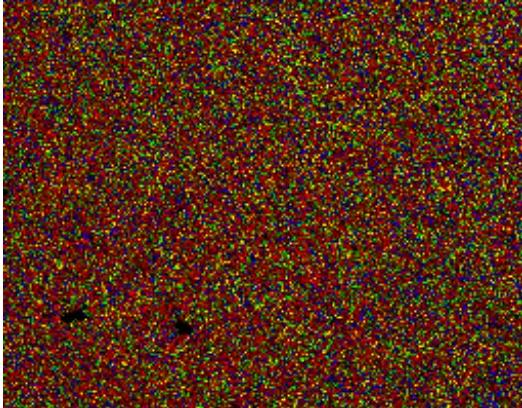
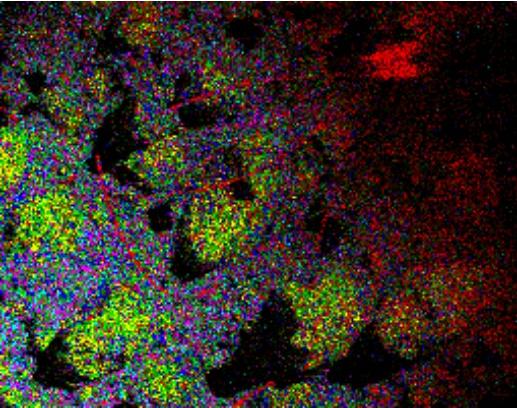
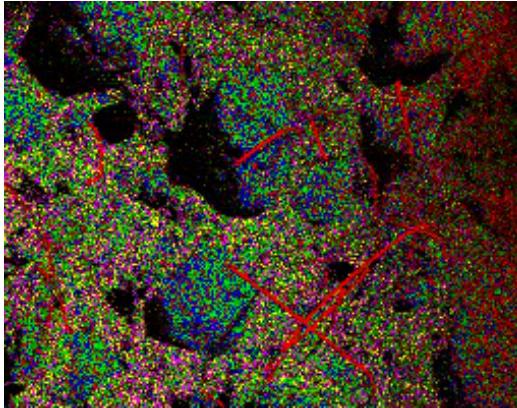
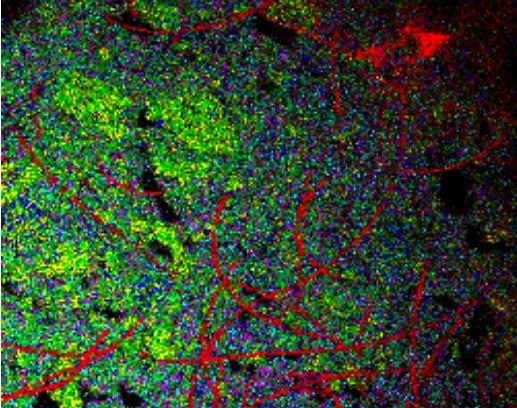
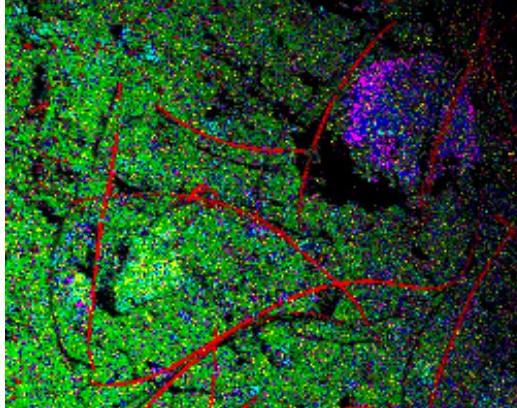
	Unexposed	No sulfur on the map. 	
	Exposed- Trial 2	Sulfur is purple. 	Sulfur is yellow. 
	Exposed-Trial 3 Manufacturer's Samples	Sulfur is purple. 	Sulfur is green. 

Table C9. Various views of cracking observed in geopolymer lining during 12-month re-evaluation on 17 Dec 2015.



Appendix D: Criteria Update Suggestions

A new specification, UFGS 33 01 30 Rehabilitation of Sewer Utilities, is being recommended to incorporate specifications for the use of geopolymer linings. It is then recommended that this new specification (UFGS 33 01 30) be referenced in UFGS 33 40 00 Storm Drainage Utilities.

DRAFT UFGS 33 01 30.71

SECTION 33 01 30.71

REHABILITATION OF SEWER UTILITIES

XX/XX

PART 1 GENERAL

Provide structural rehabilitation and corrosion resistance using a geopolymer liner system at locations indicated. The Contractor is responsible for all work related to the provision of the liner system installed, including all pertinent material and environmental site conditions.

1.1 REFERENCES

The publications listed below form a part of this specification to the extent referenced. Where reference is made to one of the standards, the revision in effect at the time of bid opening shall apply. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM) :

- ASTM C39 (2016) Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
- ASTM C78 (2015b) Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). (Note: ASTM C293 – Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading) is not a substitute test for the more conservative ASTM C78; ASTM C293 provides flexural strengths significantly higher than ASTM C78 due to relaxed loading conditions which are not appropriate for this type of structural repair.)
- ASTM C109 (2016a) Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. (or 50 mm) Cube Specimens)
- ASTM C172 (2010) Standard Practice for Sampling Freshly Mixed Concrete
- ASTM C469 (2014) Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
- ASTM C496 (2011) Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
- ASTM C666 (2015) Resistance of Concrete to Rapid Freezing and Thawing
- ASTM C882 (Type II or Type V) (2013a) Bond Strength of Epoxy-Resin Systems Used with Concrete By Slant Shear
- ASTM C1090 (2015) Standard Test Method for measuring Changes in Height of Cylindrical Specimens of Hydraulic-Cement Grout
- ASTM C1138 (1997) Standard Test Method for Abrasion Resistance of Concrete (Underwater Method)
- ASTM F2551 (2016) Standard Practice for Installing a Protective Cementitious Liner System in Sanitary Sewer Manholes

AMERICAN CONCRETE INSTITUTE (ACI) :

- ACI 305R (2010) Guide to Hot Weather Concreting
- ACI 306R (2010) Guide to Cold Weather Concreting
- ACI Certified Concrete Field Testing Technician, Level 1

NATIONAL ASSOCIATION OF SEWER SERVICE COMPANIES:
NASSCO Pipeline Assessment & Certification Program
(PACP)

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION
(OSHA) :

Regulations Standard - 29 CFR

U.S. ARMY CORPS OF ENGINEERS (USACE) :
EM 385-1-1 (2014) Safety and Health Requirements.

1.2 DEFINITIONS

Geopolymer-For the purposes of this specification, "geopolymer" describes a class of materials which are similar to traditional concretes. In general, geopolymer mixes are stronger and cure more quickly than Portland concrete. Many different classes of geopolymers exist, and the mix used will vary based on materials available and design requirements.

1.3 RELATED REQUIREMENTS

1.4 SUBMITTALS

Government approval is required for submittals with a "G" designation; submittals not having a "G" designation are [for Contractor QC approval] [for information only]. When used, a designation following the "G" designation identifies the office that will review the submittal for the Government. Submittals with an "S" are for inclusion in the Sustainability Notebook, in conformance to Section 01 33 29, SUSTAINABILITY REPORTING. Submit the following in accordance with Section 01 33 00, SUBMITTAL PROCEDURES:

SD-01 Preconstruction Submittals; G[, _____]]

(1) Site Evaluation and Pre-Installation video; G[, _____]]

(2) Site Plan; G[, _____]]

(3) Site Requirements Plan; G[,_____]]

(4) Quality Control/Quality Assurance Plan; G[,_____]]

SD-03 Product Data

(5) Geopolymer Mix Designs; G[,_____]]

(6) Geopolymer Manufacturer and Batch Data; G[,_____]]

(7) Geopolymer Mixer Equipment; G[,_____]]

(8) Conveying and Placing Equipment; G[,_____]]

(9) Cold-Weather Requirements; G[,_____]]

(10) Hot-Weather Requirements; G[,_____]]

(11) Grout and Patching Materials; G[,_____]]

(12) Safety Data Sheet for Each Material; G[,_____]]

(13) [List equipment if different than 2.2.1.2; G[,_____]]

SD-04 Test Reports

(14) Test Results of Applied Material; G[, [_____]]

(15) Post-Application Inspection; G[, [_____]]

SD-05 Design Data

Site Requirements and Structural Design;
G[, _____]]

Structural design for the liner system shall be provided by the Contractor with certification by a licensed structural engineer. Design shall consider the properties of the proposed material, expected loading, hydraulics, and other site-specific factors. Thickness of the liner, the resulting hydraulic properties, and strength must

be included.

SD-06 Closeout Submittals

(16) Records; G[, _____]

Daily Work Logs of installation operations, including records of the volume of materials removed, daily progress and grout volumes used, and as-built drawings of location and alignment of [casing] [pipeline]; G[, _____]

SD-07 Certificates

Letter of certification provided by the manufacturer that the product meets or exceeds all technical and packaging requirements.

G[, _____]

Manufacturer's original third-party verification that materials meet physical properties specified for design at 24 hours and 28 days: minimally ASTM C-78, ASTM C-39 or C-109, ASTM C-882, and ASTM C-1090 and ASTM C-666, ASTM C-11138, and ASTM C-807, as required.

Manufacturer's certifications that materials have been approved for the installation conditions shown on the drawings and as specified herein.

Manufacturer's materials warranty certificate.

Installer's warranty certificate.

Statement of Contractor Qualifications.

SD-08 Manufacturer's Instructions

(17) Installation instructions, include substrate preparations; Design G[, _____]

1.5 PRE-CONSTRUCTION

Provide all submittals to the Contracting Officer's Representative for review and approval no later than 30 days prior to commencement of the work.

1.6 QUALITY CONTROL

1.6.1 Statement Of Contractor Qualifications

Contractors are required to have proven and successful experience in installing a geopolymer liner system. The experience is the successful completion of similar projects to the tolerances indicated for the size of pipe and quantities shown on the plans. The Contractor shall be an approved installer of the geopolymer liner system as certified and licensed by the manufacturer. The Contractor shall submit documentation and verifiable references for installation of the proposed lining system in a minimum of 5,000 linear feet of large diameter (>36 inch) horizontal pipe for pipeline qualifications and a minimum of 500 vertical linear feet for manhole qualifications.

1.6.2 Records

1.6.2.1 Daily Work Log

Maintain a work log of on-site events and observations. All on-site measurements, which include all testing data should be recorded. Include the following information for each day's work at a minimum:

- a. Hours worked, including when crew members arrived and left the site.
- b. Names of certified technicians collecting samples or performing measurements.
- c. Date and time of sample collection.
- d. Water addition rate, or water setting on the mixer.
- e. Retrieval speed of the retraction system.
- f. Pump motor speed controller setting.
- g. Hose length from pump to discharge head.
- h. Temperatures
 - i. Batch water
 - ii. Dry powder before mixing
 - iii. Ambient air within the pipe or close to the application site.
 - iv. Ambient air at point of mixing
 - v. Mixed mortar
- i. Explanations of any deviations from referenced standard test methods.
- j. Curing methods- including initial curing method with maximum and minimum temperatures and final curing methods and conditions.
- k. Date and time the samples were received at the certified lab or storage facility.

- l. Summary of amount of material used and work completed.
- m. Calculated density results with data and calculations.
- n. Compressive results with data and calculations.

1.7 DELIVERY, STORAGE, AND HANDLING

Inspect materials delivered to site for damage. Unload and store with minimum handling. Store materials on site in enclosures or under protective covering. Do not store materials directly on the ground.

1.7.1 Delivery of Materials

Deliver material in Manufacturer's original unopened and undamaged package. Clearly identify manufacturer, brand name, contents and stock number on each package. Packages showing indications of damage that may affect condition of contents are not acceptable. Delivery of unmixed raw materials to the site for use is prohibited.

1.7.2 STORAGE OF MATERIALS

Store in original packaging under protective cover and protect from damage.

Store all materials at temperatures recommended by manufacturer.

Stack containers/bags in accordance with manufacturer's recommendations.

1.7.3 HANDLING OF MATERIALS

Handle materials in such a manner as to prevent damage to products or finishes.

1.8 SAFETY

1.8.1 General

Provide procedures for safe conduct of the work in accordance with EM 385-1-1. When and where installations temporarily disrupt pedestrian use of sidewalk areas for periods exceeding two consecutive work days, provide an

alternate route that meets current ABA* Accessibility Standard for Department of Defense Facilities.

Storm and sewer pipes are classified as confined spaces according to OSHA Regulation CFR 29 Part 1910.146. Personnel must be adequately trained as either a confined space entrant or attendant. Records showing the date, location, and test results of confined space training must be available upon request. It is required that Personnel use a relevant 4-gas detection meter to monitor the air quality of sewer pipe manholes before entry and are familiar with its operation. When working in Permit Required Confined Spaces (PRCS) the permit must be fully and properly filled out before any operations begin. The minimum equipment required for PRCS entry consists of a fully functional 4-gas monitor with a hose of proper length to sample all levels within the confined space (this includes the lowest level, breathing/work zone, above breathing zone and below the ceiling), a tripod in good working condition having the chains required to stabilize the legs in place, a suitable retraction device in good working order, and harnesses that fits the entrant comfortably.

Proper personal protective equipment (PPE) will be worn by the Field Technicians at all times at the work site. Proper PPE consists of minimum of a hard hat, eye protection (safety glasses, goggles, or a face shield) steel toed boots, and a reflective vest. Provide adequate lighting for the nature of the activity being conducted by workers (helmet flashlights). Additional PPE maybe required by local regulations.

Personnel involved in mixing operations must have on long sleeve shirts, gloves and appropriate dust masks while mixing the powder materials. Personnel that work near the spin cast head must wear eye protection that includes safety glasses as a minimum and a face shield for employees that wear glasses.

1.8.2 Equipment

Ensure all equipment used meets geopolymers manufacturer and mixer manufacturer safety recommendations.

* Architectural Barriers Act – applicability of 31 October 2008 to DoD facilities.

1.9 QUALITY ASSURANCE

1.9.1 Site Plan

Provide a plan prepared, signed and sealed by a licensed Professional Engineer and include the following for approval and use by the government for quality assurance.

1.9.1.1 Operational Layout

1.9.1.1.1 Layout Plan

Provide a plan location of the operation, discussing relationship of equipment, the method of liner application and details for the following:

- a. Location of all pipes to be rehabilitated.
- b. Site access including route, site configurations and details.
- c. Equipment layout including and maximum hose lengths required, and bypass pumping if required.

1.9.1.1.2 Pedestrian Access Around Site

When and where installation work disrupts pedestrian use of sidewalks for periods exceeding two consecutive days, provide an alternate route that meets current ADA requirements.

1.9.1.1.3 Traffic Access Around Site

When and where installation work disrupts use of roadways, provide an alternate route in coordination with local authorities.

1.9.1.2 Method and Procedures

Provide an outline of the methods and procedures, including drawings, schedule of operations, specifications, and manufacturer's catalog data for products in lieu of specifications, methods of operation for spray-applied geopolymer operations, and specifically the following:

- a. Site Work: Provide a plan and discussion of methods to be employed, including design drawings and calculations, sealed and signed by a licensed Professional Engineer.
- b. Mixing Equipment and Methods: Provide a discussion of the methods and equipment used for mixing operation, including

- any special requirements, and proposed procedures for removing or clearing clogged material.
- c. Spraying Equipment and Methods: Provide a discussion of the methods and equipment used for mixing operation, including any special requirements, and proposed procedures for removing or clearing clogged material.
 - d. Liner Thickness Control: Identify method and equipment to install liner and field verify within specified tolerances.
 - e. Contingency Plan: Provide a plan and discuss protection of pavements, adjacent structures, and utilities affected by the work. As a minimum, include the following:
 - i. Names, telephone numbers, and locations of persons responsible for implementation of contingency plans.
 - ii. Materials and equipment required to implement contingency plans. Identify the location of all required materials and equipment.
 - iii. Step-by-step procedure for performing work involved in implementation of the contingency plans.
 - iv. Clear identification of the objectives of the contingency plans and methods to measure plan success.

PART 2 PRODUCTS

2.1 SYSTEM DESCRIPTION

The work includes providing all labor, materials, and specialized equipment for the installation of geopolymer liner to rehabilitate pipes.

2.1.1 Design Requirements

2.1.1.1 Site Work

Provide excavations, fill, ballast, erosion control and mitigation, concrete, and other work required.

NOTE: The designer shall plan for and include any additional requirements based on local conditions. The Designer shall also determine if a separate site work specification is needed.

2.1.1.2 Design Calculations of Geopolymer Liner Thickness and Strength

Submit design calculations for the geopolymer pipe liner's thickness and strength, showing the liner system will provide the required structural performance. Include consideration of pipe, fill, and traffic loading.

Include calculation of effect on hydraulic performance of the pipe. The calculations are to be sealed by a licensed Professional Engineer.

2.2 EQUIPMENT

2.2.1 Spray-applied System

All applicable equipment calibration records must be maintained on site by the Contractor and available for inspection upon request of the Owner.

2.2.1.1 General Equipment Requirements for Preparation of Geopolymer Lining Material

A continuous automated high-shear mixing and pumping system is required to ensure consistent performance associated with maintaining consistent water/material ratio, mix time, mix speed, and dwell time prior to pumping and dwell time in the hose. Precision metering of water in a continuous mixing chamber is required to maintain the strict water to material ratio requirement. The ability to closely adjust and monitor the addition of water is required. The method of adjusting and monitoring shall be described in the Mixing Equipment and Methods section of the Quality Assurance Plan.

Mixing water temperatures must comply with manufacturer's recommendations. The Contractor shall monitor water temperature and provide mixing water meeting the requirements.

Pumping shall be achieved through an adjustable speed pump for continuous delivery to the appropriate application device. Pumps must be equipped with multiple sensors that stop the pump if material either runs out or is overflowing.

Mixed materials shall be pumped through a hose delivery system to the appropriate application device. A delivery hose shall be coupled to a high speed rotating applicator device when spin-casting is required. Maximum dwell time in the hose will conform to manufacturer's recommendations.

2.2.1.2 General Spin Casting Application of Geopolymer Lining Equipment Requirements

The rotating casting applicator shall be adjustable to properly position it within the culvert or structure.

The application equipment shall be designed to ensure a consistent coverage and thickness of the liner. This may be accomplished via a spin cast nozzle capable of bidirectional spinning operation with a reciprocating head. If the Contractor's equipment lacks these features, submit equipment description for approval equipment.

The retrieval rate of the spin head must be measurable and constant. Retrieval rate and material pumping rate shall be coordinated to ensure appropriate layer thickness is not exceeded, considering manufacturer's recommendation and good practice. The retraction device speed should be calibrated daily.

2.3 MATERIALS

2.3.1 Liner Material

Provide geopolymer, geopolymer blend, or approved equal mortar in ready-mix bags from the manufacturer for use in a suitable mixing and pumping apparatus. Material shall be commercially mass-produced for the purpose of pipe or infrastructure rehabilitation.

2.3.1.1 Material Properties

The cured material must satisfy the criteria below. Testing results shall be submitted providing third party certifications for the material proposed. Structural Design shall be submitted for approval and shall consider the physical properties of the material proposed and shall use the more conservative ASTM C78 values for Flexural Strength, not values obtained from ASTM C293.

Generally and Commonly Applicable Standards:

Maximum Sieve Size - 2.38 mm

Compressive Strength	ASTMC39 or C109	1 Day	2,000 psi
		28 Day	7,000 psi
	ASTM C78	7 Day	750 psi

Flexural Strength		28 Day	1,000 psi
Tensile Strength	ASTM C496	28 Day	570 psi
Shrinkage	ASTM C1090	28 Day	<0.07%
Modulus of Elasticity	ASTM C469	1 Day	3,000,000 psi
		28 Day	4,300,000 psi
Bond Strength	ASTM C882 Type II	1 Day	900 psi
		28 Day	2,500 psi

Freeze/Thaw Durability	ASTM C666	300 Cycles	No damage
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Set Time	ASTM C807	Initial	< 75 min
		Final	< 120 min

Abrasion Resistance	ASTM C1138	5 Cyl. 28 Day	< 3% Loss
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For chemical resistance such as sulfates, sulfides, or chlorides consider manufacturer's recommendations.

2.3.1.2 Liner Thickness

The wall thickness shall be previously calculated by the manufacturer. The manufacturer shall submit thickness calculations to a Professional Engineer for review and approval.

The minimum liner thickness, independent of design, shall be 1.0 inch for all pipes with an internal diameter of less than 54 inches for structural applications.

The minimum liner thickness, independent of design, shall be 1.5 inches for all pipes with an internal diameter of 54 inches or greater for structural applications.

The minimum liner thickness, independent of design, shall be 0.5 inches for all manholes.

2.3.1.3 Roughness and Hydraulics

The geopolymer liner is relatively smooth and the overall diameter of a culvert will be reduced. Thus, hydraulic properties must be evaluated and approved by the Owner.

2.4 INCIDENTAL MATERIALS

Additional materials including chemical grouts and hydraulic cements necessary to stop infiltration and create a surface for the geopolymer lining be applied to may be necessary.

Specific materials must be compatible with the geopolymer lining and the Owner reserves the right to require preapproval of such materials.

PART 3 EXECUTION

3.1 PREPARATION

3.1.1 Site Requirements

The Contractor shall submit a Site Requirements Plan. Include in the plan a discussion of the method of applying the liner. When applicable, address bypass pumping, slope stabilization, excavation methods, dewatering system, sheeting/shoring, and bracing systems.

3.1.2 Pipe Cleaning

Properly cleaning the surface of the pipe is critical to the success of this rehabilitation method. Inside pipes shall be kept free of dirt and debris.

The surface of the pipe to be lined shall be clean and exposed so the liner can be directly applied. All internal debris shall be removed from the pipeline or structure. Gravity pipes shall be cleaned with hydraulically powered equipment, high-velocity jet cleaners, or mechanically powered equipment. If pipe diameters allow for manned entry, the use of high-pressure washers delivering a minimum of 3500 psi shall be utilized. The use of higher-pressure washers may be required to achieve the desired surface condition. In some instances mechanical cleaning methods may be required.

When grease and oil are present within the pipe, appropriate measures shall be taken to clean the pipe. For example, water may be heated to 200 degrees, or an approved detergent may be added to the water or a dilute solution of muriatic acid may be used integrally with the high-pressure cleaning water. Proposed measures must be submitted and approved in advance.

All waste materials resulting from the cleaning of the pipe shall be appropriately removed prior to application of the geopolymer lining material.

All loose or defective concrete, brick, or grout, shall be removed to provide an even surface prior to application of the geopolymer lining material.

3.1.3 Pre-Inspection

The Contractor shall perform a pre-installation television inspection that meets NASSCO PACP requirements. The Contractor shall verify that pipe or manhole is clean and conditions are suitable for installation of the geopolymer liner.

Utilizing a color video inspection system (CCTV) with data recording capabilities, the entire pipe section to be lined shall be recorded on CD or DVD and two (2) copies produced. The interior of the pipe shall be carefully inspected to determine the location of any conditions, which may prevent the proper installation of the geopolymer liner and it shall be noted so that these conditions can be corrected. A CD, DVD or other digital recording and suitable log shall be submitted to the Owner.

For each existing service connection determined by the Owner to be active, the Contractor shall recommend an approach for installing the liner in that area. The Owner shall consider the recommendations and approve the approach to be used.

The Contractor shall notify the Contracting Officer's Representative if conditions exist which will impact the installation.

If pre-installation video inspection using PACP certified operators reveals an obstruction in the line segment (such as heavy solids, dropped joints, protruding

service connections or collapsed pipe) that cannot be removed by conventional sewer cleaning equipment, perform point repairs or obstruction removal prior to the geopolymer liner installation. Obtain approval of the Contracting Officer's Representative before performing work.

3.1.4 Preparation and Pre-Lining Repairs

If the cleaning process reveals that the pipe invert, crown or sidewalls are deteriorated, measures will be taken to provide a continuous slope to the pipe, including the use of a flow-able fill or the introduction of wall lining material onto the pipes surface.

Any open joints will be sealed with the geopolymer lining material prior to the lining of the pipe.

Active leaks must be sealed prior to application of the lining material. All products employed in the stoppage of active leaks should be preapproved by the Contracting Officer's Representative and used in accordance with Manufacturer's recommendations.

If additional repair procedures must be undertaken by the Contractor to prepare the existing structure for lining a plan shall be submitted for approval of the Contracting Officer's Representative prior to proceeding.

The Contractor shall accurately field measure and size each individual manhole. The Contractor is reminded that each existing sewer manhole designated to receive the lining may have a different configuration and varying field dimensions.

The Contractor shall accurately field measure and size each individual pipe section. The Contractor is reminded that each existing sewer designated to receive the lining may have a different configuration and varying field dimensions.

The Contractor is advised that the presence or absence of leakage through manhole walls is dependent upon the ground water levels and conditions at the time of the inspections. All leakage shall be stopped prior to lining any structures.

The geopolym liner should not be placed when the ambient temperature is 37°F and falling or when the temperature is anticipated to fall below 32°F during the next 24 hours, unless specific precautions are employed.

Refer to ACI 305R-99 Hot Weather Concreting. Do not apply geopolym liner material when ambient and surface temperatures are 100°F or 35°C and above. Shade the material and prepare the surface to keep it cool. To extend working time, follow manufacturer's recommendations. Be certain the substrate is saturated surface dry (SSD) before application begins.

3.1.5 Bypass Pumping

As required for acceptable completion of the work or to avoid damages due to sewer spills or overflows, the Contractor shall provide for sewage conveyance around the section or sections of pipe designated for rehabilitation.

The bypass shall typically be made by plugging the line at an existing upstream structure and pumping the flow into a downstream structure or adjacent system.

The pump and bypass lines shall be of adequate capacity and size to handle the maximum anticipated flow rate.

Bypassing of sanitary sewage into the storm water system will not be allowed. For all bypass pumping, equipment noise shall be kept to a minimum.

3.3 INSTALLATION

3.3.1 Mixing Geopolymer Liner Material

Mix geopolym liner material according to manufacturer's instructions and maintain the recommended water ratio throughout the application process. The water temperature must be recorded in the field and must comply with manufacturer's recommendations.

3.3.2 Application of Geopolymer Lining

The application of the specified geopolym liner material consists of spray applying and/or centrifugally spin-casting the material to the inside of an existing structure. The necessary equipment and application meth-

ods to apply the liner materials shall be only as approved by the material Manufacturer and in accordance with Section 2.2. Material shall be mixed in accordance with Manufacturer's specifications to proper consistency, then the materials shall be pumped through a hose for delivery to the application device.

The rotating applicator shall be positioned at the pipe center, or otherwise positioned and maintained inside the pipe, depending on pipe diameter and shape, to achieve uniform liner thickness.

Spraying shall be performed by starting at the pipe end-project location and retracting the spin case assembly at a monitored uniform rate. The retrieval rate of the spin head must be measurable and constant. At the beginning of each pipe segment the retraction device shall be calibrated. The rate measured must be recorded and be within 5% of the expected speed.

The geopolymer lining material shall be applied to a damp surface, with no standing or flowing water. The rotating applicator head shall travel and spray to provide a uniform material thickness. Maximum layer thickness shall conform to manufacturer's recommendations and good practice. Once applied, no movement such as sags or runs is permissible.

Multiple passes shall then be made until the specified uniform minimum finished thickness is attained. If the material supply is interrupted, the operator shall arrest the retrieval of the applicator head until material flow is restored.

When the pipe is sufficiently out of round, hand spray application of the geopolymer lining may be necessary, and the delivery hose shall be coupled to a hand spray application assembly. Hand spraying shall be performed by starting at the bottom of the structure and progressing up the wall.

The hand spray assembly and the centrifugal spin casting head may be used in combination to ensure uniform application of the material, accounting for irregularities in the contour of the pipe walls.

If desired, the geopolymer liner may be troweled following the spray application. Initial troweling shall be in

an upward motion, to compress the material and solidify the pipe wall. Precautions shall be taken not to over-trowel. Only a wood float or magnesium (Mg) float should be utilized.

3.3.4 Curing of Geopolymer Lining

Follow the manufacturer's recommended cure schedule in curing the geopolymer liner. The material must be allowed to cure a minimum of 2 hours or until the material has reached an initial set condition, whichever is longer, prior to the restoration of water flow through the pipe.

Proper steps shall be taken to ensure the material is cured in a moist and moderate climate. Underground conditions are usually adequate to meet this curing requirement. However, when conditions are dry or hot, the use of a wind barrier, fogging spray, or other approved measures may be required.

In cold weather, refer to ACI 306R-88 Cold Weather Concreting. Low substrate and ambient temperatures slow down the rate of set and strength development. At temperatures below 45°F or 7°C, warm the material and monitor substrate temperatures. Properly ventilate the area when heating. Protect the new liner from freezing in the first 6 hours after application.

3.3.5 Termination and Sealing

Termination of the geopolymer liner at the end of a lined area shall be completed in a workmanlike manner and in accordance with manufacturer's recommendations.

3.3.6 Restoration of Lateral or Service Connections

All existing active connections shall be reopened after the liner is applied. Restored connections shall be neatly and smoothly open and without rough edges. Care must be exercised not to damage the geopolymer lining while reinstating the connection.

3.3.7 Ventilation

Provide adequate ventilation for all tunnels and shafts, following confined space entry procedures. Test the air in areas accessed by workers in accordance with the most

current OSHA methods and standards. See also Section 1.8.

3.4 TOLERANCES

3.4.1 Thickness

Verify the specified minimum thickness has been achieved by the following methods:

- a. Indicator tabs or screws- Attach small plastic indicator tabs or screws positioned at the specified thickness prior to applying the material. These serve as a reference point for the thickness; the indicators shall be completely covered by the installed liner and will be left in place.
- b. When it is not practical to place indicator tabs or screws, the Contractor may propose an alternate method of verifying the liner thickness. The method shall be submitted to the Contracting Officer's Representative for approval.
- c. When measures a. and b. do not verify the specified minimum thickness, the Contracting Officer's Representative may request cores be taken from the installed liner marked with the date the liner was installed, the date the core was removed, and the location from which it was taken. The average thickness measured shall be taken as the actual thickness of the liner. If the average thickness is not above 90% of the specified minimum thickness, the liner is considered out of tolerance.

3.4.2 Compressive Strength

Verify the compressive strength requirements though a licensed third party laboratory. If samples collected are not above the 28 day compressive strength required by the certified structural design, the liner is considered out of tolerance.

3.5 FIELD QUALITY CONTROL

Employ the quality assurance plan. Maintain daily records in accordance with the paragraph titled RECORDS.

3.5.1. Mandatory Requirements

Record in the daily work log all observations required. Clearly identify work not meeting specified requirements, or out-of-tolerance results.

3.5.2 Field Sample Collection and Laboratory Tests

Perform field tests and provide labor, equipment, and incidentals required for testing. Field tests include,

at a minimum, temperature and compressive strength. Collect samples in accordance with ASTM C172. Measure temperature in accordance with ASTM C1064. Compressive strength testing shall be performed in accordance with ASTM C39 by an independent ACI certified testing agency after 24 hours and 28 days (additional samples may be held for retesting at 56 days if necessary). Testing frequency shall include the first and last day of construction and once for every 40,000 pounds of dry geo-polymer material applied.

Submit test results, and identify any results that do not meet specified requirements identified in the certified structural design to the Contracting Officer's Representative within four days of test completion. Provide corrective action as recommended by the geopolymer manufacturer, subject to approval by the Contracting Officer's Representative.

3.5.3 Inspections

Prior to the removal of equipment and re-opening the pipe or structure for use, conduct CCTV inspection of the mains installed and produce two (2) copies.

NOTE: Designer should determine inspection methods depending on size and accessibility of the pipe, along with type of utility piping involved, and local conditions.

3.6 CLEANUP AND FINAL CLOSEOUT

3.6.1 Site Cleanup

Upon completion of rehabilitation work and testing, clean and restore project area affected by the work equal to existing conditions prior to installation, unless otherwise indicated.

3.6.2 Records of Daily Work Logs

Submit an electronic copy and three hard copies of the records to the Contracting Officer's Representative within five days after completing the work. Maintain and submit upon completion final Daily Work Logs of installation operations, signed by the superintendent.

3.7 DISPOSITION OF MATERIAL

Dam and absorb spillages with sand, earth, or other non-combustible material. All geopolymers waste materials should be packaged, labeled, and transported to a disposal facility in accordance with all national, state/provincial, and local requirements and product characteristics at time of disposal.

-- End of Section --

Draft Criteria Change Request to Update UFGS 33 40 00

Below is the draft wording to specifically update the note on page 5 of UFGS 33 40 00, so that a reference to the geopolymers liner rehabilitation mechanism is included in UFGS 33 40 00.

DIVISION 33-UTILITIES

SECTION 33 40 00

STORM DRAINAGE UTILITIES
XX/XX

NOTE: This guide specification covers the requirements for storm drainage piping systems using concrete, clay, steel, ductile iron, aluminum, polyvinyl chloride (PVC), polyethylene (PE), and polypropylene (SRPE) pipe.

Prior to replacing piping system components, rehabilitation methods should be considered, including no-dig geopolymers liner technology. See UFGS Section 33 01 30, "Rehabilitation of Sewer Utilities" for more information.

Adhere to UFC 1-300-02 Unified Facilities Guide Specifications (UFGS) Format Standard when editing this guide specification or preparing new project specification sections. Edit this guide specification for project-specific requirements by adding, deleting, or revising text. For bracketed items, choose applicable items(s) or insert appropriate information.

Remove information and requirements not required in respective project, whether or not brackets are present.

Comments, suggestions, and recommended changes for this guide specification are welcome and should be submitted as a Criteria Change Request (CCR).

REPORT DOCUMENTATION PAGE

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14. ABSTRACT <p>Many metal pipes and culverts on Department of Defense (DoD) installations are deteriorating due to corrosion. Repair often requires excavation, including roadways above culverts—a costly, messy, and disruptive approach. This project successfully demonstrated and validated a geopolymer liner system at Fort Bragg, NC. The evaluation focused on strength, corrosion resistance, and implementation to ultimately recommend use of geopolymer liners for DoD stormwater and wastewater infrastructure. A new Unified Facilities Guide Specifications (UFGS), UFGS 33 01 30.71 Rehabilitation of Sewer Utilities, was created to guide adoption of this technology, and a draft criteria reference request was created for UFGS 33 40 00 Storm Drainage Utilities. Caution is advised, however, for using a geopolymer liner in extremely acidic environments. Testing showed that geopolymer material provided higher compressive strength than typical concrete. Acid resistance could not be verified, however, although the product still may be suitable in wastewater environments. The primary advantage of a geopolymer liner is its ability to create a new structural pipe within the old, deteriorating pipe—a no-dig approach that saves costs. The geopolymer liner also provides other benefits such as no cold joints, faster cure time, and less down time. The project's return on investment is 7.73 over 30 years.</p>					
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